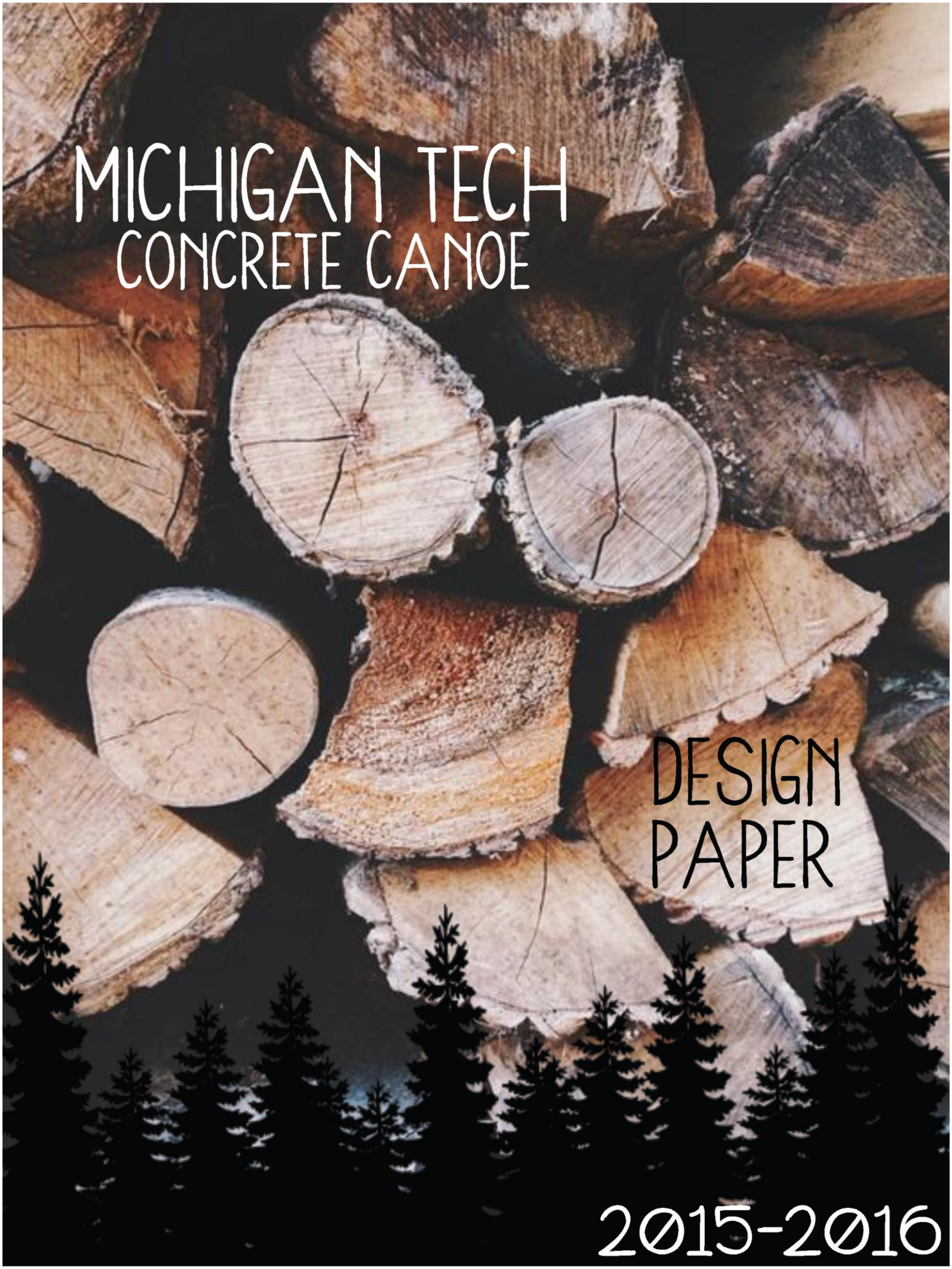

MICHIGAN TECH
CONCRETE CANOE

DESIGN PAPER

2015-2016

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Executive Summary

Deep in the heart of the American landscape lies a land of unfathomable natural beauty. The National Park Service, established in 1916, is a federal agency that preserves and protects over 84 million acres of this land (National Park Service 2016b). To celebrate its 100th birthday, National Parks was chosen as the 2016 theme (National Park Service 2016a). The largest mountain in North America resides in an Alaskan national park. For nearly a hundred years, the mountain has been federally recognized as Mount McKinley. Last year, it was changed back to its native name given by the Koyukon people centuries ago (Davis 2015). To honor the return of an American mountain to its prideful, indigenous name, Michigan Technological University is proud to present—*Denali*.

Michigan's Upper Peninsula is home to Michigan Technological University (Michigan Tech) in the small, historical town of Houghton. The Concrete Canoe team at Michigan Tech has been a member of the North Central Student Conference since 1992. The team has taken 1st place at the regional competition for the past six years. Recently, the team has placed 7th, 8th, and 11th in the 2013, 2014, and 2015 national competitions, respectively. A summary of the team's membership and competition statistics is found in Table 1.

The 2015-2016 season introduced innovative designs and practices to build upon the successes of Michigan Tech's 2nd lightest boat to date, *Talvi Sielu* (MTU 2015). The hull design committee developed a design that would increase the canoe's stability and turning ability. A scenario was added to this year's structural analysis to model paddler weight shifts during a buoy turn. The research and development (R&D) committee achieved a binary blend of Class C fly ash and portland cement. An alternative material was selected as this year's primary reinforcement for its percent open area and economic sustainability. The aesthetics committee implemented contemporary finishing techniques to improve inlay and outlay methods. A new project management system was established to organize projects through their life cycles. These innovations led to the successful completion of *Denali*. Furthermore, the paddling team researched and practiced various buoy turn methods. Tables 2 and 3 summarize the physical properties of the team's final product.

Table 1: Michigan Tech Statistics

Michigan Tech Membership and Competition Statistics
9 **The 35-member team is comprised of nine majors: eight engineering majors and one non-engineering major.**
6 **Michigan Tech has placed first at the regional level for the past six years.**
7th · 8th · 11th **In the past three years, the team placed highly at the national level.**

Table 2: Properties of the 2015-2016 Canoe

Denali	
Estimated Weight:	162 pounds
Color:	Beige
Length:	19.0 feet
Width:	30.8 inches
Depth:	15.1 inches
Nominal Thickness:	0.375 inches
Primary Reinforcement:	5mm Basalt Mesh
Secondary Reinforcement:	Nycon-PVA RF4000 Nycon-PVA RECS15

The national park system is an untouched and pristine wilderness representing the American pioneering spirit. With these innovations Michigan Tech captures the natural beauty and splendor of this spirt in its final product of *Denali*.

Table 3: Properties of the 2015-2016 Concrete Mixtures

Mixture	Unit Weight (pcf)		Strengths (psi)			Air Content (%)
	Wet	Dry	Compressive	Tensile	Flexural	
Structural	58.6	54.1	1600	400	1390	12.7
Finishing	92.1	88.3	1420	250	90	8.1
Inlay/Outlay	58.2	53.8	1350	350	860	14.0
Pigmented Finishing	93.0	88.5	1410	240	80	8.3

Project Management

The 2015-2016 Michigan Tech Concrete Canoe team endeavored for strong leadership and teamwork, balanced with innovative ideas and professional communication. An organizational structure (Page 3) was established to guarantee successful project completion.

Michigan Tech's leadership consists of three captains: two senior captains and one junior captain. In addition to the three captains, a compliance chair, a safety chair, and a treasurer were elected. The compliance chair oversaw the team's operations to verify that the 2016 rules and regulations were followed (ASCE/NCCC 2016). The safety chair monitored material testing, construction processes, and paddling practices as part of the safety program. This year, a treasurer position was added to the team's organizational structure to strengthen the economic forecasting and cash flow monitoring of the entire project. In addition to the chairs, five committees led the team through project completion: engineering, aesthetics, academics, research & development, and paddling.

The safety chair introduced a three tier program to ensure the safety of all members. First, it mandated that all committees meet with the safety chair to identify the necessary personal protective equipment to use for each respective task. Secondly, in order to operate machinery, team members attended training sessions. Finally, "toolbox talks" were implemented to understand personal hazards for the ensuing tasks to be completed.

A new project management system was utilized by committee leaders to define their project's life cycle. This system is comprised of four phases: conceptualization, planning, execution, and termination (CPET), as described in Figure 1 (Pinto and Kharbanda 1995). In the first phase, conceptualization, committee leaders and members identified specific goals. The next phase, planning, consisted of research and testing in which the team also obtained quotes for budgetary purposes. These materials were procured and the project was completed in the third phase, execution. In the last phase, termination, processes are reviewed and knowledge is recorded and transferred. While using the CPET system, committee leaders were encouraged to incorporate the team's motto into the design process: refinement, innovation, compliance, and knowledge transfer.

Milestones established in the conceptualization phase, summarized in Table 4, were used to create project schedules for each committee. Committee schedules were combined using precedence and logic to construct an overall project schedule. The overall schedule highlights actual start and finish dates along with any delays. The critical path was determined by selecting milestones that, if delayed, would affect the entire project schedule (Page 11). The project accounted for 2,170 labor hours, which is shown in Figures 2 and 3 on the Project Management Resource Allocation section (Page 2).

Table 4: Major Milestones

Task	Planned	Actual
Mixture Selection	11/2/2015	11/2/2015
Mold Procurement	11/24/2015	11/24/2015
Casting	1/15/2016	2/1/2016
Demolding	1/30/2016	2/15/2016

This year, the team budgeted $25,000 for the design, construction, and competition. The funds were acquired from Michigan Tech academic departments, donations from sponsors, and fundraising events held by the team. A summary of the team's income and expenses are shown in Figure 4 in the Project Management Resource Allocation section.

One of the team's objectives for the 2015-16 year was to emphasize social, economic, and environmental sustainability. To improve the team's social sustainability, greater efforts were made to transfer knowledge and lay a foundation for future success. Maintaining and establishing connections with alumni and local companies was imperative to the economic sustainability of Michigan Tech's team. Environmental sustainability was applied to the mixture design by optimizing the batch sizes to eliminate waste during testing and construction.

Project Management Resource Allocation

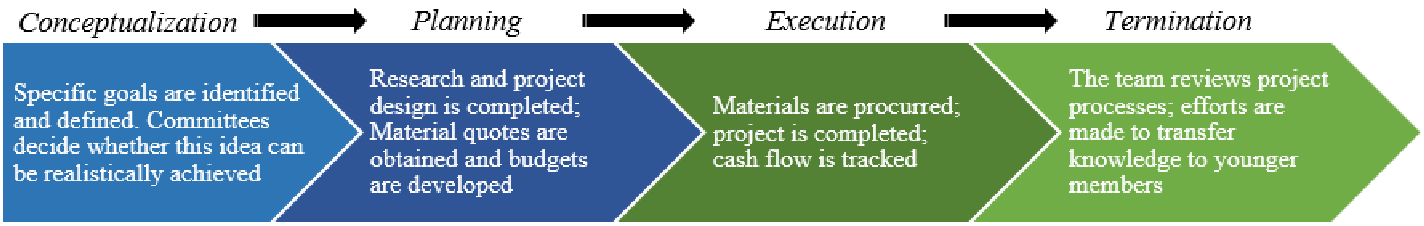


Figure 1: CPET Project Management Flowchart

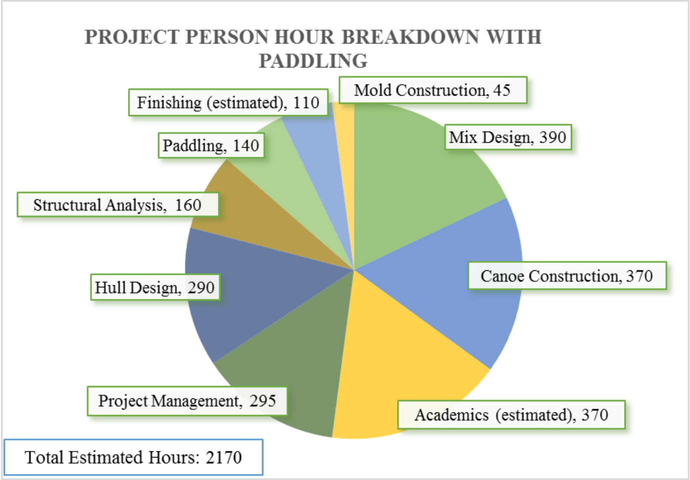


Figure 2: Person Hours with Paddling - This displays the breakdown of hours spent by the team on all aspects of the project, including paddling. Paddling accounts for 140 of the total 2170 hours.

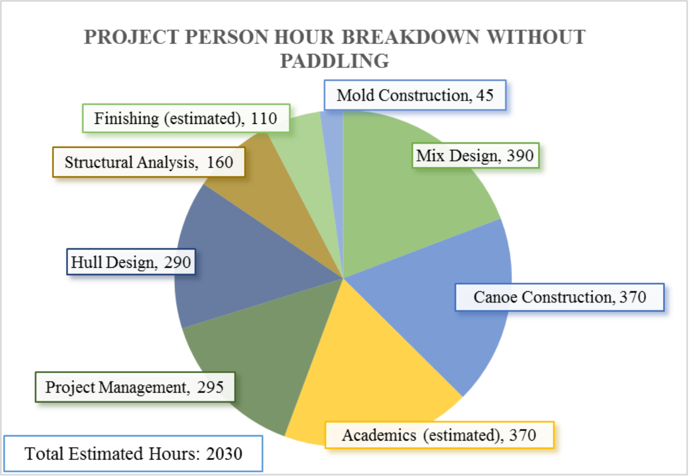


Figure 3: Person Hours without Paddling - This displays the breakdown of 2030 hours spent by the team on all aspects of the project, not including paddling

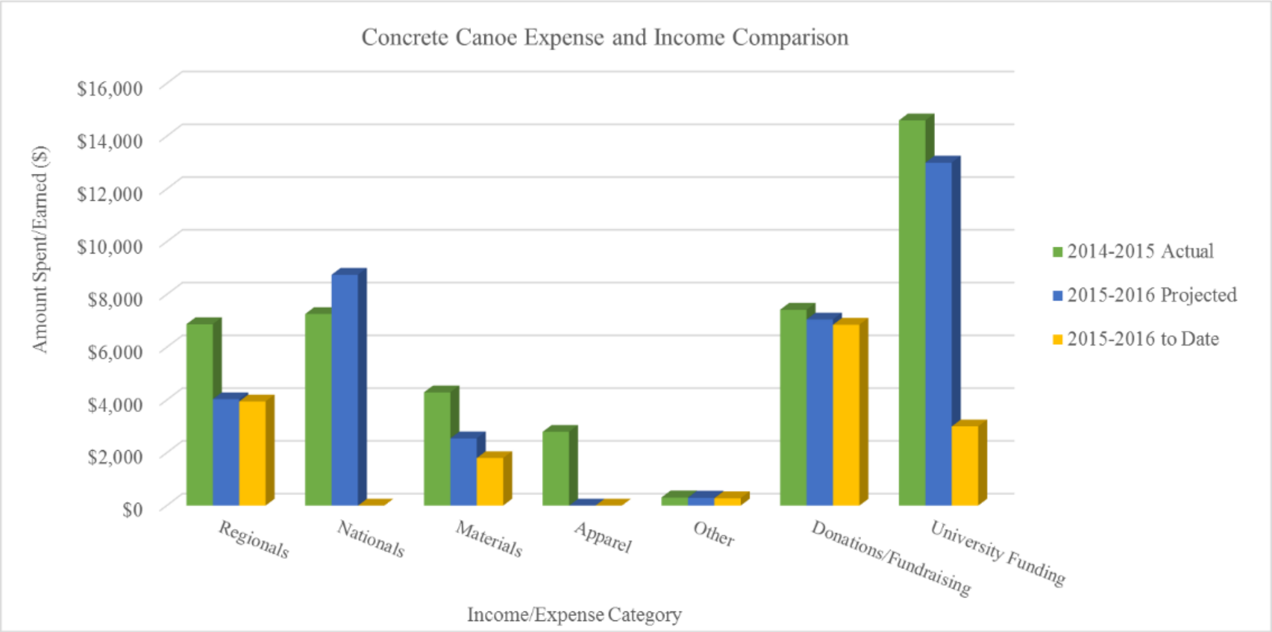
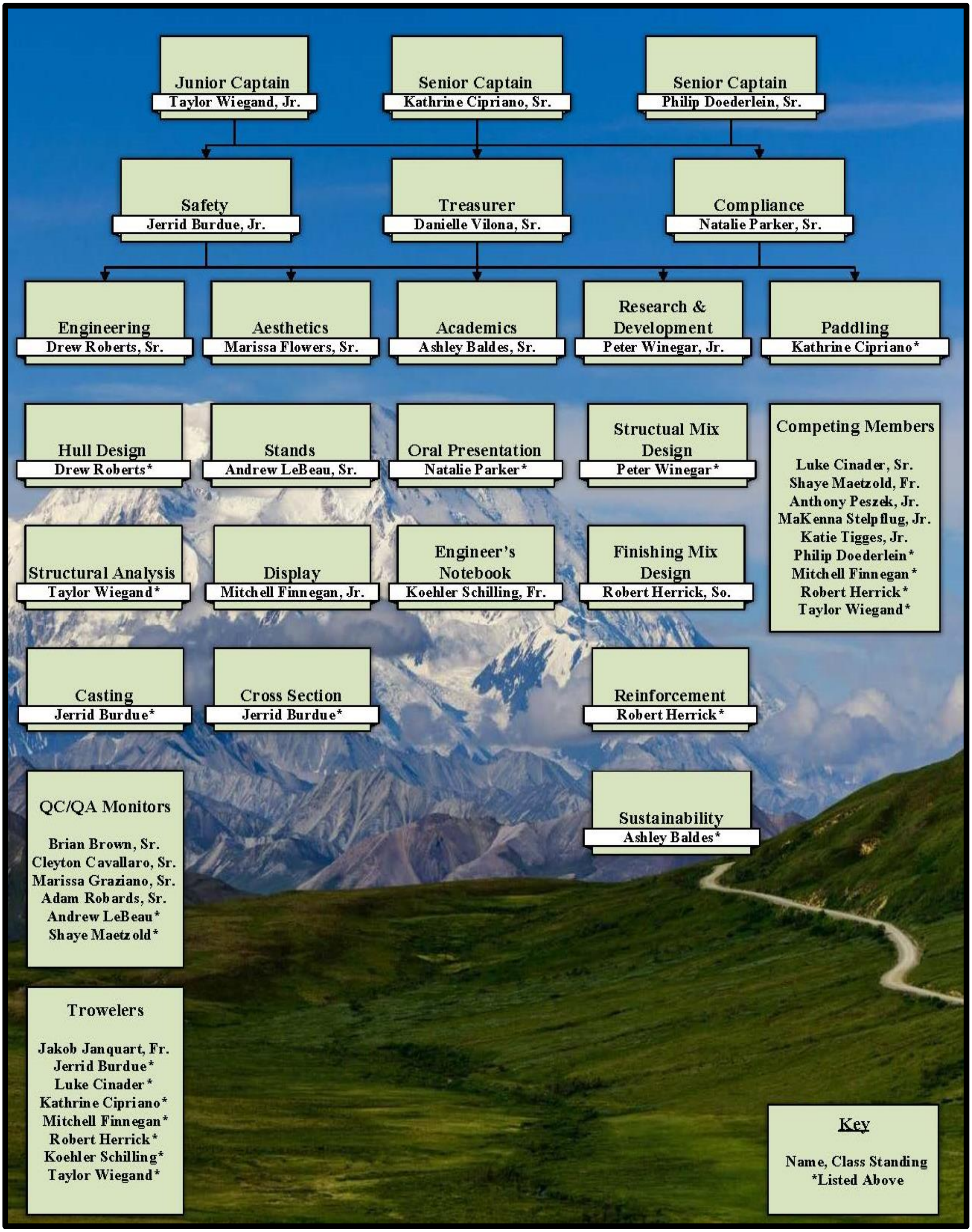


Figure 4: Concrete Canoe Budget Comparison - This compares the actual budget from 2014-2015 with the actual and projected budgets for 2015-2016

Organizational Chart



Junior Captain
Taylor Wiegand, Jr.

Senior Captain
Kathrine Cipriano, Sr.

Senior Captain
Philip Doederlein, Sr.

Safety
Jerrid Burdue, Jr.

Treasurer
Danielle Vilona, Sr.

Compliance
Natalie Parker, Sr.

Engineering
Drew Roberts, Sr.

Aesthetics
Marissa Flowers, Sr.

Academics
Ashley Baldes, Sr.

Research & Development
Peter Winegar, Jr.

Paddling
Kathrine Cipriano*

Hull Design
Drew Roberts*

Stands
Andrew LeBeau, Sr.

Oral Presentation
Natalie Parker*

Structual Mix Design
Peter Winegar*

Competing Members

Luke Cinader, Sr.
Shaye Maetzold, Fr.
Anthony Peszek, Jr.
MaKenna Stelpflug, Jr.
Katie Tigges, Jr.
Philip Doederlein*
Mitchell Finnegan*
Robert Herrick*
Taylor Wiegand*

Structural Analysis
Taylor Wiegand*

Display
Mitchell Finnegan, Jr.

Engineer's Notebook
Koehler Schilling, Fr.

Finishing Mix Design
Robert Herrick, So.

Casting
Jerrid Burdue*

Cross Section
Jerrid Burdue*

Reinforcement
Robert Herrick*

QC/QA Monitors

Brian Brown, Sr.
Cleyton Cavallaro, Sr.
Marissa Graziano, Sr.
Adam Robards, Sr.
Andrew LeBeau*
Shaye Maetzold*

Sustainability
Ashley Baldes*

Trowelers

Jakob Janquart, Fr.
Jerrid Burdue*
Luke Cinader*
Kathrine Cipriano*
Mitchell Finnegan*
Robert Herrick*
Koehler Schilling*
Taylor Wiegand*

Key

Name, Class Standing
*Listed Above

Hull Design and Structural Analysis

The engineering committee worked to develop a canoe that would improve performance during races. To achieve this, the hull design committee increased the stability and turning ability of the canoe, while minimizing reductions to straight-line tracking and speed. The structural analysis committee studied the effect of paddler weight shifts during co-ed race turning scenario.

Hull Design

To design the 2016 canoe, *Denali*, the team began with an analysis of the previous year's canoe, *Tavli Sielu*. A review of paddler feedback revealed concerns regarding the stability of *Talvi Sielu*. The canoe's structural performance at races was also analyzed. During the 2015 races, significant cracking developed while in the buoy turn of the co-ed race. This resulted from high freeboard, causing paddlers to lean against the canoe walls while turning. A sharp change in cross sectional area led to stress concentrations, further propagating the crack. These observations formed the hull design goals of improving stability and increasing turning ability.

The stability and turning ability of *Genoa* (MTU 2012) were incorporated into *Talvi Sielu's* hull design to create the baseline of *Denali*. PROLINES 98 (Vacanti Yacht Design LLC. 1998) was used to model *Denali's* final geometry. First, the hull design committee increased beam width to enhance turning ability and provide a more gradual change in cross sectional area. This is evident by a 6% decrease from last year in the length to beam (L/B) ratio. Next, the concave hull was replaced with a rounded bottom hull. Finally, the committee decreased freeboard allowing paddlers to lean further while turning. The hull properties of *Genoa*, *Talvi Sielu*, and *Denali* are compared in Table 5.

To quantify design goals, this year's hull design committee used the righting moment (RM) to judge the canoe's stability. The RM is the moment the canoe will exert to return the center of buoyancy (B) in line with the center of gravity (G) after the canoe has heeled to a specific angle. As a canoe heels, its center of buoyancy changes, creating a moment arm (G_z) in respect to the center of gravity. Figure 5 below shows the shift in the center of buoyancy and the resulting moment arm (Sailboat Cruising).

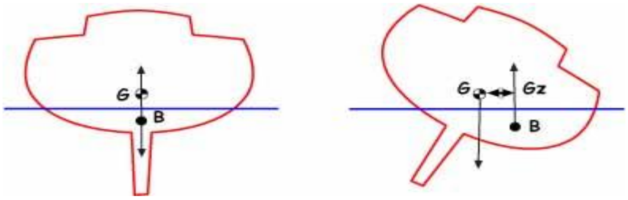


Figure 5: Buoyancy Shifts

The canoe's righting moments (RM) were calculated using Equation 1 (Tupper 2013). In this equation, the displaced weight is equal to the weight of the canoe and the paddlers.

$$\mathrm{RM} = G_z * \text{Displaced Weight} \qquad \text{(EQ 1)}$$

An increase in RM indicates greater stability as the canoe exerts more energy against the heeling motion. Figure 6 displays the increase in RM of *Denali* from previous year's hull designs. Using this analysis, *Denali* was determined to have achieved the hull design committee goals.

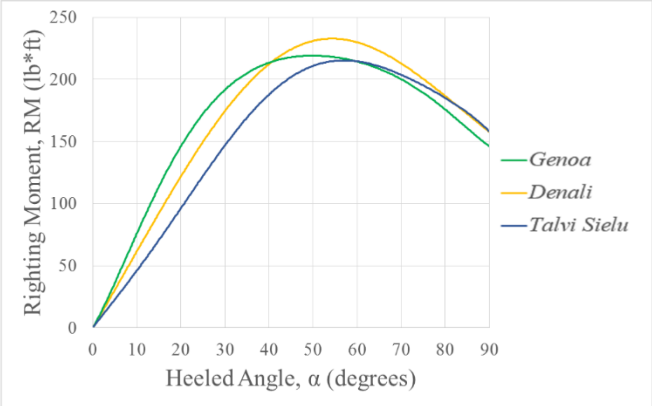


Figure 6: Righting Moment Comparison

Table 5: Comparison of Hull Properties

	Length	Wetted Beam Width	L/B Ratio	Freeboard	Rocker		Maximum RM
	(ft)	(in)	(ft/ft)	(ft)	Bow (in)	Stern (in)	(lb*ft)
Genoa	18.5	30.4	7.9	0.289	1.5	1.0	127.9
Talvi Sielu	19	27.3	8.3	0.631	4.0	3.0	124.2
Denali	19	29.1	7.8	0.545	4.2	3.1	135.7

Structural Analysis

The structural analysis committee set a goal to improve accuracy of this year's model in order to set required design strengths. The team reviewed previous years analyses utilizing spline curve points in Siemens NX 10 (Siemens PLM Software 2015). Using NX 10, 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). Overlaps and gaps between the rectangles were accounted for and gunwale caps were added. This process was repeated along the length of the canoe for all one inch cross sections. Areas, centroids, and second area moments of inertia were calculated based on these combined components. *Denali* was modeled assuming a nominal thickness of 3/8 inch and a unit weight of 54 pounds per cubic foot (pcf).

The structural analysis committee analyzed three non-race loading cases. A transportation load scenario was modeled as a distributed load on the canoe while secured inside the trailer. A display stand loading case was modeled as a uniform distributed load (canoe self-weight) resting on two supports used for displaying the canoe. A simply supported beam loading case was modeled similarly with the supports located to resemble two people holding the canoe, one on each end. Three race loading scenarios of men's, women's, and co-ed paddling teams were also modeled. Straight-line dynamic loading conditions were assumed when calculating stresses. The male and female paddler weights were modeled as 200 and 170 pounds, respectively. To account for dynamic loading, these weights were increased by 20%. Two linearly distributed loads represented each paddler in both kneeling and sitting positions. The kneeling load was split 63%-37%, while the sitting load was split 17%-83% between the front and rear contact lengths.

Buoyancy forces were then calculated for each race load case and the canoe was trimmed until static equilibrium was met. Shear and bending moments were calculated at one inch increments along the length of the canoe, see Figure 7.

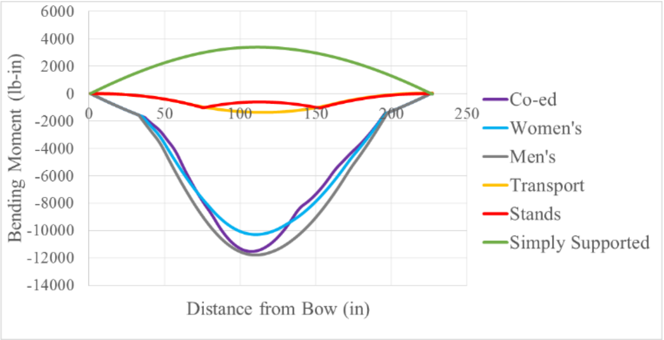


Figure 7: Bending Moment Envelope Diagram

Stresses were computed at each cross section maximum tensile and compressive stresses being recorded. The maximum flexural stresses were calculated for *Denali* are summarized in Table 6. A maximum compressive stress of 145 pounds per square inch (psi) was located 11 feet from the bow, while a maximum tensile stress of 122 psi was located 11.8 feet from the bow. Sample calculations are presented in Appendix C.

Table 6: Maximum Stresses Calculated

Load Case	Maximum Tension (psi)	Maximum Compression (psi)
Men's	122	145
Women's	108	128
Co-ed	114	129
Transportation	27	22
Display Stands	22	21
Simply Supported	46	43

To improve the analysis the committee incorporated a simple transverse load case for a turning scenario. Testing showed that a paddler shifted 74.6% of their weight to the respective turning side of the canoe during a buoy turn. Analyzing the co-ed race, design moments were calculated from the applied force to the center of the canoe in respect to the paddler's center of gravity. A required moment capacity of 15,170 in-lb was calculated for two bow paddlers in the co-ed race.

Due to last years race performance, a minimum safety factor was increased to 3 to ensure Denali would withstand the rigors during races. Thus, required concrete mixture design strengths of 435 psi compressive and 366 psi tensile, and a composite moment capacity of 45,510 in-lb were established.

Development and Testing

Michigan Tech's R&D committee built upon past research, testing, and experiences to establish its baseline goals. The committee developed a concrete mixture that met the strength demands set by structural analysis, while incorporating previous mixture designs and exploring new materials. From previous years' experience, the committee recognized the need for two layers of continuous reinforcement to provide adequate punching shear strength. Additionally, a new reinforcement material, 5 mm Basalt Mesh, was tested to replace the previously used Kevlar® 4009-1. By incorporating previously used and new materials, the R&D committee established the mixture design and reinforcement scheme for *Denali*.

Mixture Design

The mixture design committee explored three concepts this year. These concepts were: to create a Class C fly ash (ASTM C618) and portland cement (ASTM C150) binary blend, to research and test new basalt fibers, and to test an alternate polymer modifier. The objective of these concepts was to increase the mixture strength while minimizing the increase in unit weight.

Michigan Tech studied previous mixture design documents to find that the highest strengths for structural concrete mixtures were reported in 2008. This structural mix, Wild Card, used in *Gambler* (MTU 2008), was taken as the baseline for testing. For each concrete mixture tested, the compressive strength (ASTM C39), split tensile strength (ASTM C496), and unit weight (ASTM C138) were recorded. Strength tests were performed at 7 and 14-day intervals and logged for each batch.

After reviewing the baseline mixture design, a binder blend of Class C fly ash and portland cement, similar to that used in Wild Card, was selected. Class C fly ash was considered as it aids in a lower heat of hydration. This allows for increased reaction time and results in greater strength development. (Mamlouk and Zaniewski 2011). This blend of 50% portland cement and 50% Class C fly ash is significantly different from last year's mixture, Loska (MTU 2015). Loska utilized a blend of portland cement, VCAS™ pozzolans, and blast furnace slag. In the past, VCAS™ pozzolans and blast furnace slag were used for their white color. However, a white color was not desired for this year's finishing process, which allowed for the elimination of these two components. After testing the Class C fly ash and portland cement blend, the strength results proved to meet the desired strength and an equal blend was chosen for this year's mixture design.

In previous years, the mixture design committee allotted three weeks in the testing schedule to cast and test aggregate blends of three main aggregates: Poraver® 1-2 mm, 0.5-1 mm, and 0.25-0.5 mm. To condense the team's mixture testing schedule and save on cost, an aggregate blend was chosen from six of Michigan Tech's previous structural mixtures, *Yooper* (MTU 2010), *Frontier* (MTU 2011), *Genoa*, *Mesektet* (MTU 2013), *Katsuo Maru* (MTU 2014), and *Talvi Sielu*, can be seen in Figure 8. Historical data was compiled starting in 2010, the first year that these three aggregates were introduced to the team. The data was analyzed to determine the distributions of six different blends of Poraver® gradations. After reviewing the data, the average percentage for each Poraver® aggregate was chosen.

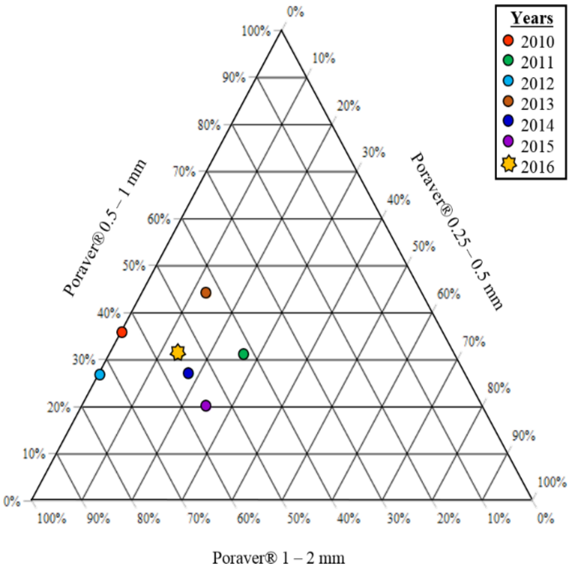


Figure 8: Poraver® Blends Used From 2010-2016

With a final blend of Poraver® aggregates, 3M™ K-1 was tested and the optimum percentage was added to the aggregate blend.

The team desired to find a replacement for the Nycon-PVA RF4000 fibers because of difficulties experienced during troweling and finishing. After researching new fibers, 3 mm Basalt Chopped fibers were tested. These fibers are shown in Figure 9. Various combinations of 3 mm Basalt Chopped fiber, Nycon-PVA RF4000, and Nycon-PVA RECS15, were explored. When compared to the Nycon-PVA fiber blends, the 3 mm Basalt Chopped fibers displayed poor fiber distribution. This distribution caused the cylinders cast with 3 mm Basalt Chopped fibers to have a loose bond between the fibers and the concrete, creating a weak point in the matrix. These defects resulted in crumbling during testing. As a result, the mixture design committee choose to remove 3 mm Basalt Chopped fibers from the final fiber blend.

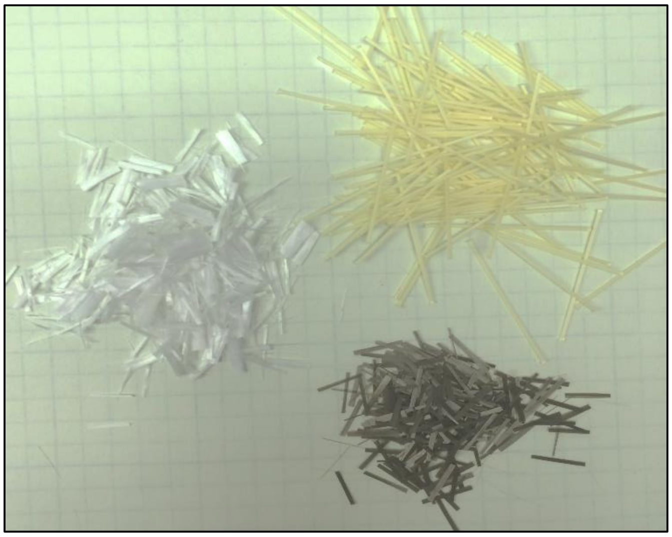


Figure 9: Fibers Tested by the R&D Committee

Additionally, Styron A™/NA was tested as a new admixture. Testing showed that the use of this admixture greatly increased the yield of the mixture. This increase in yield correlated with decreases in compressive and split tensile strengths. These strengths were significantly less than mixtures without Styron A™/NA. Xypex® Xycrilic had been used by the team in previous years. From empirical testing, the admixture demonstrated increased strengths and workability in test batches. Based on previous experience, BASF Glenium 3030 NS, a super plasticizer, was deemed necessary for this year’s mixture design. Xypex® Xycrilic and BASF Glenium 3030 NS were chosen as the final admixtures and Styron A™/NA was excluded.

During the research and development process for Old Faithful, *Denali*’s structural mixture, the team looked to decrease its environmental impact. The largest area for improvement was the amount of excess concrete created when batching. To reduce the amount of wasted concrete, batch sizes were optimized.

This year’s mixture design committee contributed 340 hours to create *Denali*’s final structural mixture, Old Faithful. Old Faithful uses a binder blend of 50% Class C fly ash and 50% portland cement which varies from previous years’ mixtures. The 2016 aggregate blend includes Poraver® 1-2 mm, 0.5-1 mm, 0.25-0.5 mm, and 3M™ K-1. The admixtures Xypex® Xycrilic and BASF Glenium 3030 NS were incorporated into the final mixture to provide strength and workability. To develop a finishing mixture, Old Faithful was modified to omit Nycon-PVA fibers and include finer aggregates. The unit weight strength test results are listed can be seen in Table 7.

Table 7: Comparison of Historical Structural Strengths

Structural Mixture	Unit Weight (pcf)	Compressive Strength (psi)	Split Tensile Strength (psi)
Wild Card (2008)	59.4	3278	603
Loska (2015)	53.9	1520	340
Old Faithful (2016)	54.1	1600	400

With this final mixture design, the committee was able to achieve all goals of creating a binary binder blend, researching and testing new basalt fibers, and testing an alternate polymer modifier. This led to Old Faithful meeting all benchmarks set by the structural analysis committee.

Continuous Reinforcement

Since 2012, Michigan Tech has used Kevlar® 4009-1 as the primary reinforcement throughout the canoe. This year, the reinforcement committee set a goal to find a new reinforcement that offered comparable strength, maximized open area, and was economically sustainable.

Research led to the procurement of a 5 mm Basalt Mesh. The tensile strengths of previous years were researched to select a 2016 reinforcement grid. The 5 mm Basalt Mesh had a tensile strength of 720 kips per square inch (ksi), while the Kevlar® 4009-1 reinforcement had a tensile strength of 530 ksi. To measure these differences, a puncture test was used to determine the basalt fiber composite strength, in comparison to Kevlar® 4009-1. Square plates, 12 inch by 12 inch, were troweled to the same thickness and placement standards that were used during the casting process. A 1.5 inch diameter puncture cylinder applied load to the plates until failure (ASTM D7136), shown in Figure 10. Maximum stresses were calculated of the composite showing the basalt mesh within a 3% overall strength capacity when compared to Kevlar® 4009-1.


Figure 10: Composite Puncture Testing

In addition to strength, the percent open area, aggregate clear cover, and sustainability of the materials were compared. The 5 mm Basalt Mesh had a 62.6% open area, which was a significant increase from the 42% open area that Kevlar® 4009-1 offered. This increase is crucial for better concrete bonding between layers of reinforcement during casting.

Reinforcement used in previous years provided minimal aggregate clear spacing. To quantify this, the reinforcement committee used the American Concrete Institute (ACI) Building Code Requirements for Structural Concrete (ACI 2014). Kevlar® 4009-1 was unable to meet ACI spacing requirement 25.2.1, in terms of 4/3 the largest aggregate diameter. However, the 5 mm Basalt Mesh met this clear spacing requirement promoting better bonding between layers.

As an added benefit, basalt mesh is more economical than the Kevlar® 4009-1. Based on the calculated amount of required reinforcement, the procurement of basalt mesh resulted in a 66% reduction of reinforcement material cost.

In addition to adequate strengths, the open area and cost made the basalt mesh a viable option, as seen in Table 8. The 5 mm Basalt Mesh was chosen as the continuous reinforcement for *Denali*. The team was able to achieve the reinforcement committee's goal of providing comparable strength, maximizing open area, and becoming economically sustainable.

Table 8: Comparison of Kevlar® 4009-1 and 5 mm Basalt Mesh

	Kevlar® 4009-1	**5 mm Basalt Mesh**
Advantages	Easier placement during casting	More open area; less expensive; allows for greater aggregate clear cover
Disadvantages	Less open area, more expensive	Has not been previously used

To ensure the composite met the benchmarks set by the structural analysis committee, the Rule of Mixtures was used to calculate a design moment capacity of the composite. A moment of 38,120 in-lb was calculated with one layer of reinforcement in the walls. This yielded a safety factor of 2.5, which was determined to be insufficient. Adding an additional layer of reinforcement in the walls brought the design moment capacity to 54,960 in-lb. With this, the safety factor increased to 3.6 and the committee deemed it adequate to meet the requirements set forth by the structural analysis.

Construction

The construction of *Denali* was completed in three phases: preparation, casting, and finishing. A full scale practice canoe was cast during the preparation phase, allowing the team to gain experience with new finishing and integral aesthetic techniques.

Preparation

After the hull design committee finalized the hull design, a high-density polystyrene foam mold was ordered. This material was chosen for its machinability, low cost, and durability. The final design was CNC-milled into the foam, 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 using wooden blocks along the bottom edges to prevent movement during casting. A design incorporating the National Parks theme was created using traction tape inside the mold. This process left indents in the concrete for pigmented finishing mixes to be placed.

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. After this, eight trowelers were assigned to separate sections of this years canoe, including two end caps sections. QC/QA monitors developed 3D-printed depth gages to check concrete thickness. A full scale casting practice was added to the project schedule to validate improved casting techniques. During this event, trowelers practiced placing concrete over traction tape. Additionally, the mixture design committee tested a new batching sequence to improve the production rate of troweling.

Materials were measured and placed into individual bags prior to casting to account for the inclusion of all mixture components and the consistency between batches. End caps for *Denali* were assembled from polystyrene foam to balance floatation due to a heavier finishing mix. Additional foam was cut into strips and coated in epoxy to create gunwale cap molds. The 5 mm Basalt Mesh reinforcement was divided into sections to cover two full layers. Careful preparation led to an efficient and successful casting of *Denali*.

Casting

Casting day began with a full team meeting, led by the captains and safety chair, to remind members of the safety program and to highlight potential hazards involved with the casting process. The facility was cooled to 50 °F to prevent cold joints from forming in the concrete. While the casting team applied release aid to the mold, the mixture design committee prepared the first batches of concrete. The QC/QA monitors assisted the trowelers in placing each 1/8 inch layer of structural concrete. Reinforcement sections were then positioned to cover the length of the boat. This process was repeated to result in a final matrix composed of three equal layers of concrete and two layers of reinforcement, creating a final thickness of 3/8 inch. Examples of concrete and reinforcement placement are shown in Figures 11 and 12, respectively.

Figure 11: Concrete Placement

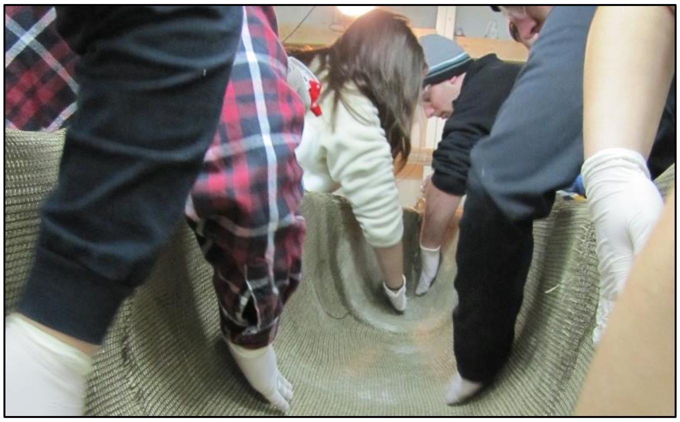


Figure 12: Reinforcement Placement

After the body of the canoe was cast, the foam end caps were added and troweled with concrete. Release aid was applied to the gunwale cap molds, which were then secured into place. To cast the gunwale caps, a thin layer of concrete was troweled into the mold. The top edge of the reinforcement was then folded over and the remaining space was filled with concrete. This completed the construction of *Denali*. An example of troweling the gunwale caps can be seen in Figure 13.

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 concrete hydration. Following the curing period, the canoe was removed from the mold and prepared for finishing techniques.

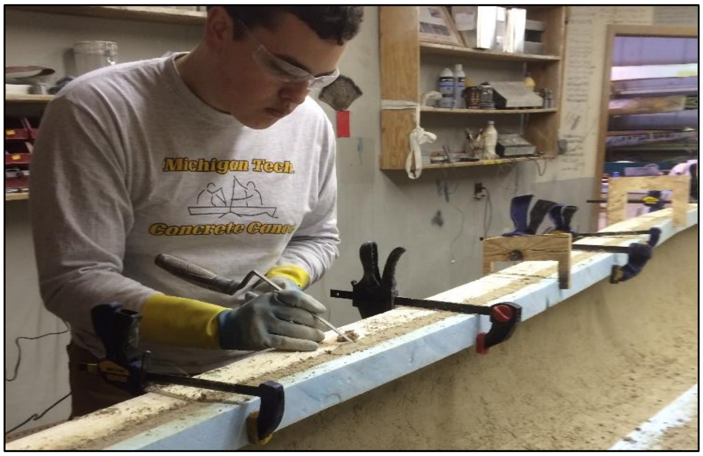


Figure 13: Troweled Gunwale Caps

Finishing

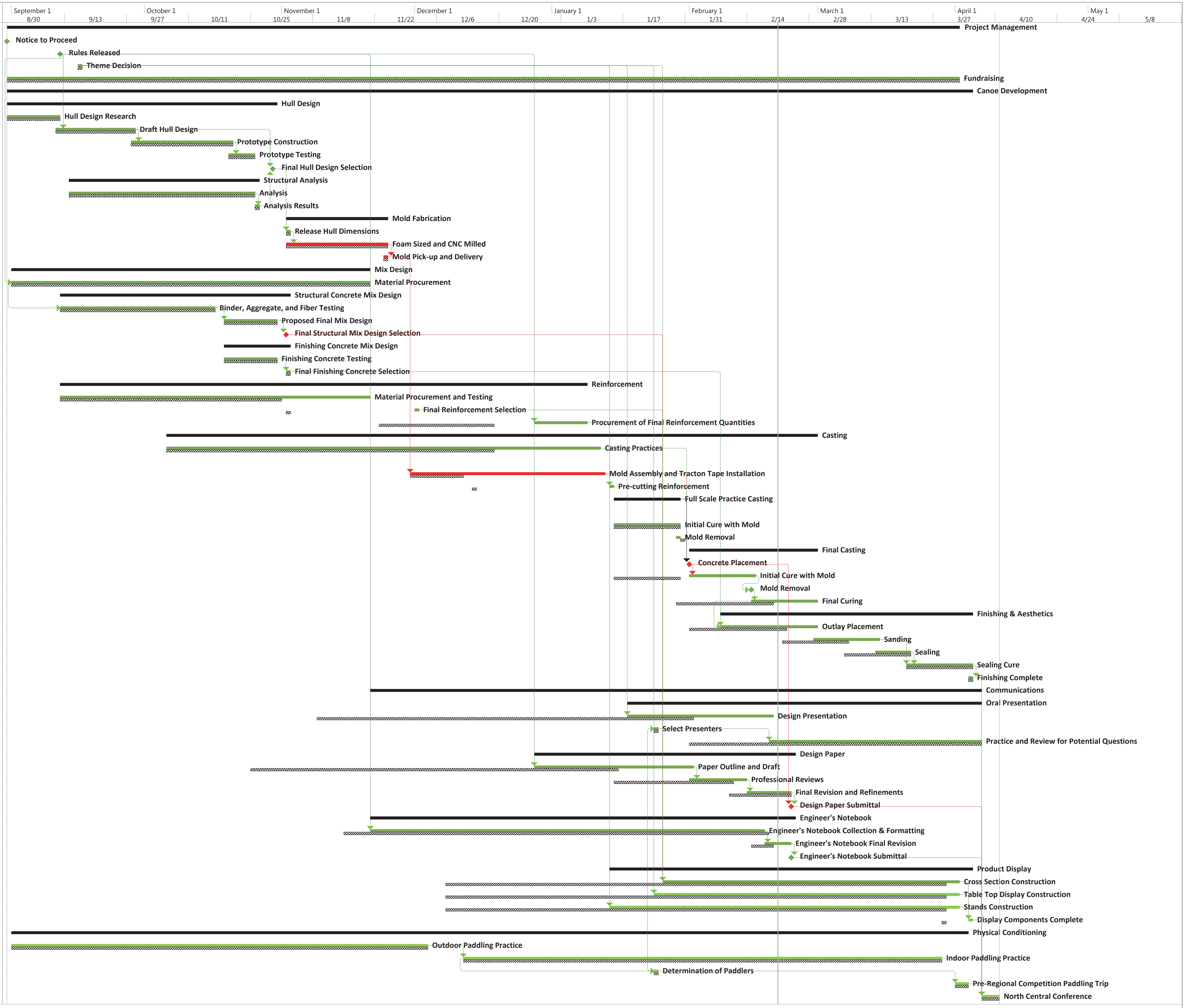
The finishing process of *Denali* began with the exterior of the canoe. Painters tape was placed to outline indents that were created by the traction tape during the construction phase. This process was implemented to protect the beige structural mix when the pigmented concrete was applied. The indents were then filled in with a finishing mixture and stamped with a stylized silicone stamp to form the concrete into a 3D design. After stamping the finishing mixture, painters tape was applied to cover the inlays and protect them while finishing the remaining exterior of the canoe. A non-pigmented finishing mixture was applied to the exterior of the canoe, to create a smooth finish. Exterior sanding began with 80 grit sand paper and was gradually increased to 1000 grit. The canoe was frequently cleaned using compressed air. As a safety precaution, dust was removed using vacuums and an air ventilation system. Lastly, vinyl decals of the university and canoe name were applied to the exterior.

The interior inlays and outlays were detailed by rotary sanding a 1/16 inch deep indent in the shape of their corresponding designs. The same concrete placement techniques applied to the exterior were used to finish the interior of the canoe. The interior aesthetic design includes a variety of different colored concrete. A thin layer of pigmented finishing mixture concrete was placed in a taped area and allowed to cure. Following, a second thin layer of pigmented mix was applied. To achieve a consistent finish, a non-pigmented finishing mix was troweled along the interior of the canoe. This layer was sanded using the same methods as the exterior.

After sanding was finished, the canoe was prepared for the application of ChemMasters® Crystal Clear A. Two coats of sealer were applied and per manufactures suggestions in order to protect the final product from water penetration and to enhance aesthetics. Finally, the sealer was wet sanded with 1000 grit sand paper providing a smooth finish.

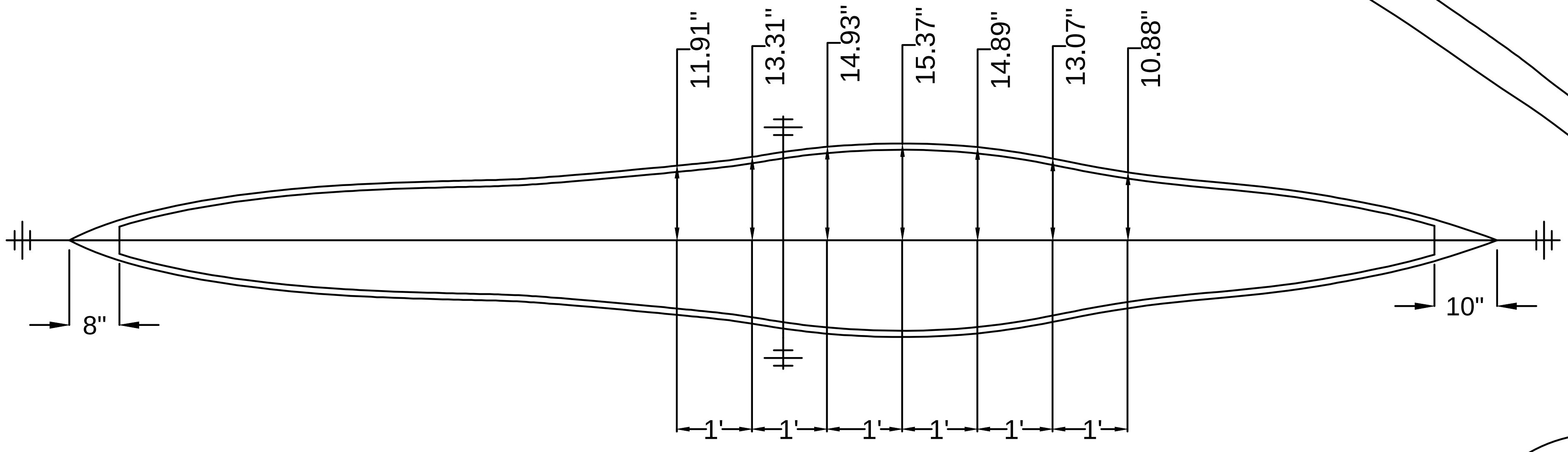
With these final touches, *Denali* was completed. Michigan Tech used inspiration from the American national parks to create a final product that embodied the pioneering spirit and awe inspiring landscape that is ingrained into the American soul.

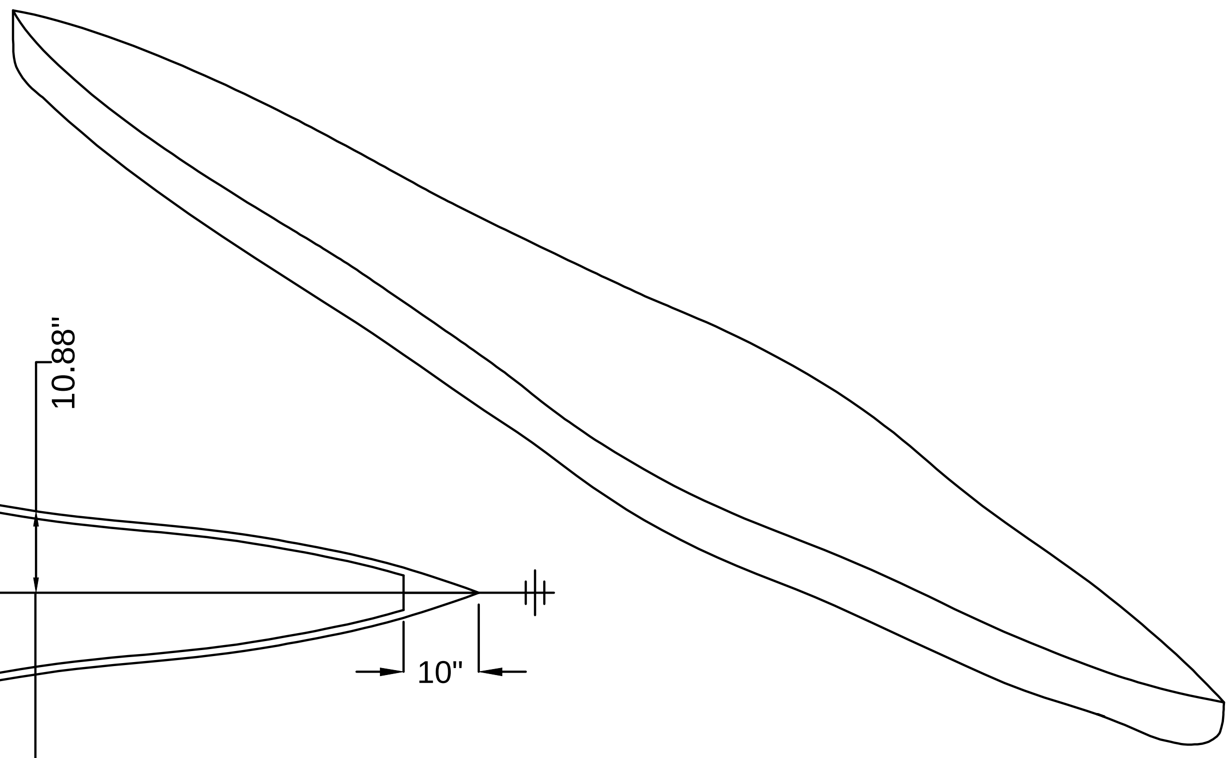
ID	Task Name	Baseline Start	Baseline Finish	Actual Start	Actual Finish
1	**Project Management**	**Mon 8/31/15**	**Fri 4/1/16**	**Mon 8/31/15**	**Fri 4/1/16**
2	Notice to Proceed	Mon 8/31/15	Mon 8/31/15	Mon 8/31/15	Mon 8/31/15
3	Rules Released	Sat 9/12/15	Sat 9/12/15	Sat 9/12/15	Sat 9/12/15
4	Theme Decision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

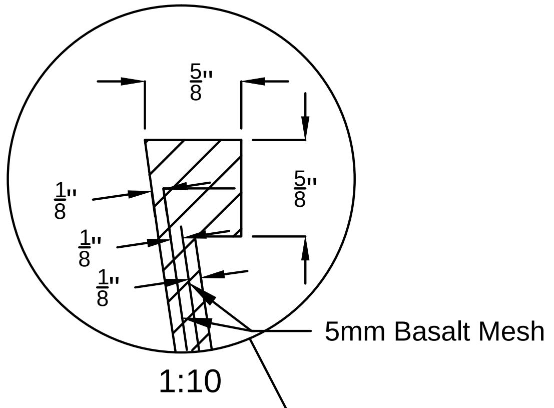


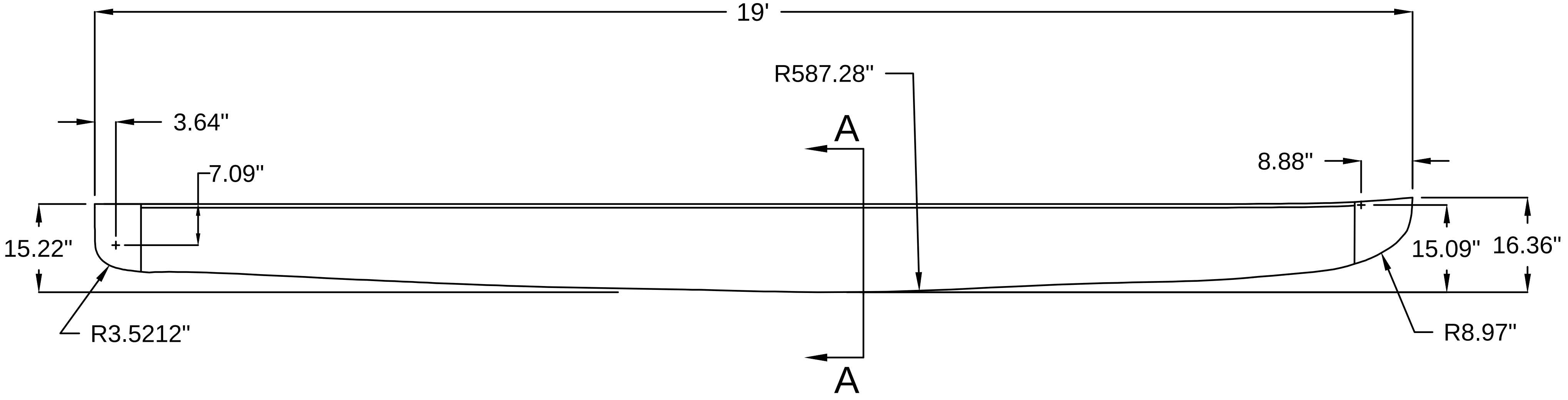
Summary ▬ Actual ▬ Baseline ▨ Milestones ◆ Critial Path ▬

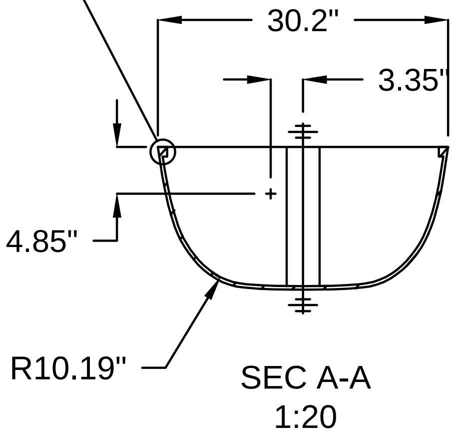
Michigan Tech Concrete Canoe Project Schedule 2015-2016











SEC A-A
1:20

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

DENALI

BILL OF MATERIALS

I.D.	DESCRIPTION	QTY.
1	FEDERAL WHITE TYPE I PORTLAND CEMENT	45.3lb
2	CLASS C FLY ASH	45.3lb
3	NYCON® RECS15 (8MM) PVA	1.11lb
4	NYCON® RF4000(8MM) PVA	0.957lb
5	XYPEX® XYCRILIC-ADMIX	2.08lb
6	BASF GLENIUM® 3030 NS	0.081gal
7	SBS-5mm BASALT MESH	175ft²
8	DOW® EXTRUDED POLYSTYRENE FOAM	2ft³
9	3M™ K-1	5.06lb
10	PORAVER® 1.0-2.0mm	23.5lb
11	PORAVER® .05-1.0mm	13.0lb
12	PORAVER® 0.25-0.5mm	5.87lb
13	PORAVER® 0.1-0.3mm	0.292lb
14	DIRECT™ COLORS CONCRETE PIGMENTS	2.0lb
15	CHEMMASTERS® CRYSTAL CLEAR-A	1.0gal
16	3M 471 VINYL TAPE	4ft²

CONSTRUCTION DRAWING

DRAWN BY: ROBERT HERRICK	SCALE: 1:25 OR AS NOTED
CHECKED BY: PHILIP DOEDERLEIN	SHEET: 12
DATE: 2/24/2016	

Appendix A: References

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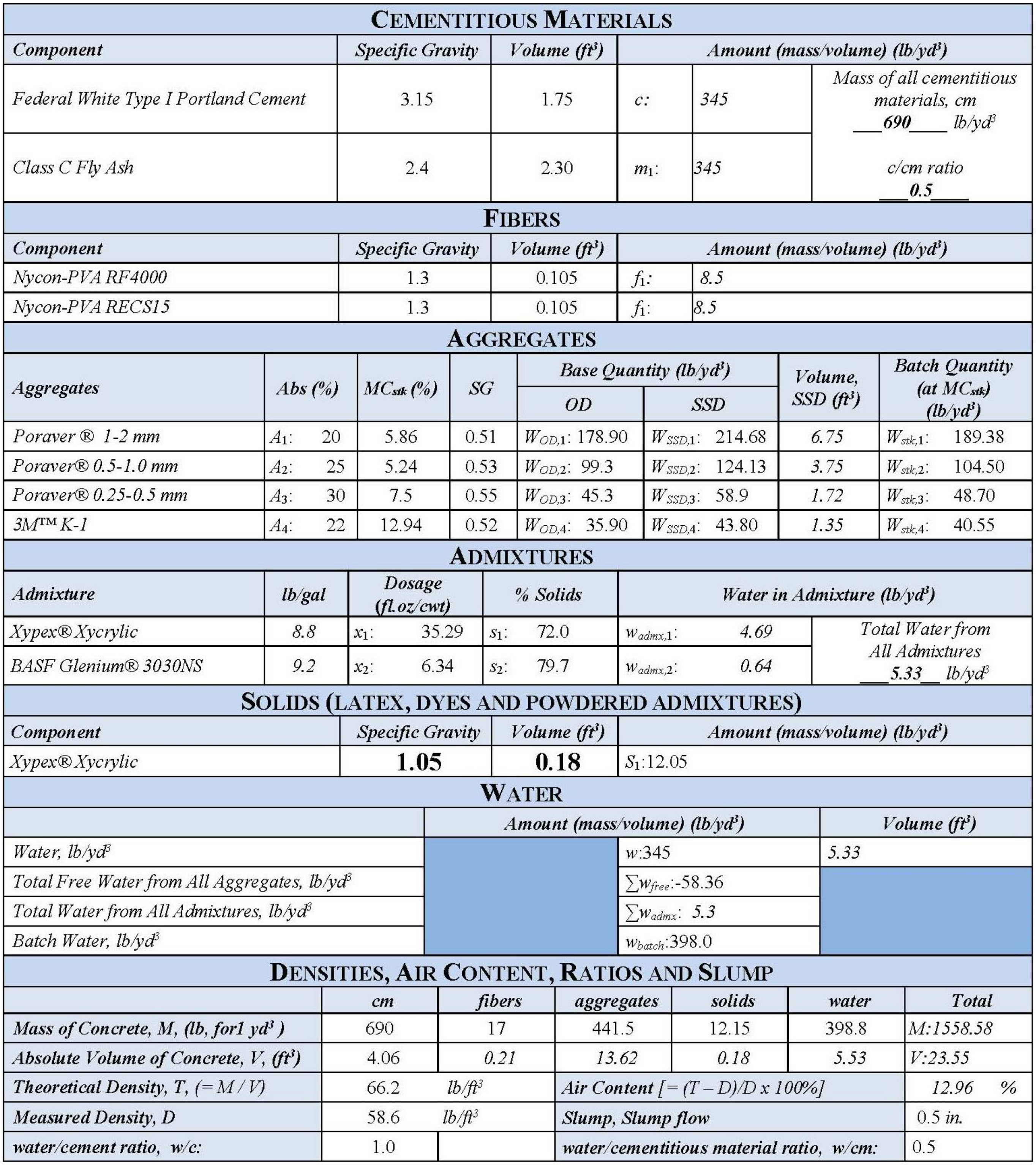
Font Approval:

Cipriano, Kathrine. “Font Approval.” Message to Jake Luedecke. 11 Feb. 2016. E-mail.

Appendix B: Mixture Proportions

Structural Mixture:



CEMENTITIOUS MATERIALS

Component	*Specific Gravity*	*Volume (ft^3)*	*Amount (mass/volume) (lb/yd^3)*		
Federal White Type I Portland Cement	3.15	1.75	*c:*	*345*	*Mass of all cementitious materials, cm* *___**690**___ lb/yd^3*
Class C Fly Ash	2.4	2.30	m_1:	*345*	*c/cm ratio* *___**0.5**___*

FIBERS

Component	*Specific Gravity*	*Volume (ft^3)*	*Amount (mass/volume) (lb/yd^3)*	
Nycon-PVA RF4000	1.3	0.105	f_1:	*8.5*
Nycon-PVA RECS15	1.3	0.105	f_1:	*8.5*

AGGREGATES

Aggregates	*Abs (%)*	*MC$_{stk}$ (%)*	*SG*	*Base Quantity (lb/yd^3)*		*Volume, SSD (ft^3)*	*Batch Quantity (at MC$_{stk}$) (lb/yd^3)*
				OD	*SSD*		
Poraver ® 1-2 mm	A_1: 20	5.86	0.51	$W_{OD,1}$: 178.90	$W_{SSD,1}$: 214.68	*6.75*	$W_{stk,1}$: 189.38
Poraver® 0.5-1.0 mm	A_2: 25	5.24	0.53	$W_{OD,2}$: 99.3	$W_{SSD,2}$: 124.13	*3.75*	$W_{stk,2}$: 104.50
Poraver® 0.25-0.5 mm	A_3: 30	7.5	0.55	$W_{OD,3}$: 45.3	$W_{SSD,3}$: 58.9	*1.72*	$W_{stk,3}$: 48.70
3M™ K-1	A_4: 22	12.94	0.52	$W_{OD,4}$: 35.90	$W_{SSD,4}$: 43.80	*1.35*	$W_{stk,4}$: 40.55

ADMIXTURES

Admixture	*lb/gal*	*Dosage (fl.oz/cwt)*	*% Solids*	*Water in Admixture (lb/yd^3)*	
Xypex® Xycrylic	*8.8*	x_1: 35.29	s_1: 72.0	$w_{admx,1}$: *4.69*	*Total Water from All Admixtures* *___**5.33**__ lb/yd^3*
BASF Glenium® 3030NS	*9.2*	x_2: 6.34	s_2: 79.7	$w_{admx,2}$: *0.64*	

SOLIDS (LATEX, DYES AND POWDERED ADMIXTURES)

Component	*Specific Gravity*	*Volume (ft^3)*	*Amount (mass/volume) (lb/yd^3)*
Xypex® Xycrylic	**1.05**	**0.18**	S_1:12.05

WATER

	Amount (mass/volume) (lb/yd^3)		*Volume (ft^3)*
Water, lb/yd^3		w:345	*5.33*
Total Free Water from All Aggregates, lb/yd^3		$\sum w_{free}$:-58.36	
Total Water from All Admixtures, lb/yd^3		$\sum w_{admx}$: *5.3*	
Batch Water, lb/yd^3		w_{batch}:398.0	

DENSITIES, AIR CONTENT, RATIOS AND SLUMP

	cm	*fibers*	*aggregates*	*solids*	*water*	*Total*
Mass of Concrete, M, (lb, for1 yd^3)	690	17	441.5	12.15	398.8	*M:1558.58*
Absolute Volume of Concrete, V, (ft^3)	4.06	*0.21*	*13.62*	*0.18*	*5.53*	*V:23.55*
***Theoretical Density, T,** (= M / V)*	66.2	*lb/ft^3*	***Air Content** [= (T – D)/D x 100%]*			*12.96 %*
Measured Density, D	58.6	*lb/ft^3*	***Slump, Slump flow***			0.5 *in.*
water/cement ratio, w/c:	1.0		***water/cementitious material ratio, w/cm:***			0.5

Finishing Mixture:

CEMENTITIOUS MATERIALS

Component	*Specific Gravity*	*Volume (ft³)*	*Amount (mass/volume) (lb/yd³)*		
Federal White Type I Portland Cement	3.15	4.06	*c:*	*798*	*Mass of all cementitious materials, cm* ___***1596***___ *lb/yd³*
Class C Fly Ash	2.4	5.33	m_1:	*798*	*c/cm ratio* ___***0.5***___

FIBERS

Component	*Specific Gravity*	*Volume (ft³)*	*Amount (mass/volume) (lb/yd³)*	
N/A				

AGGREGATES

Aggregates	*Abs (%)*	*MC$_{stk}$ (%)*	*SG*	*Base Quantity (lb/yd³)*		*Volume, SSD (ft³)*	*Batch Quantity (at MC$_{stk}$) (lb/yd³)*
				OD	*SSD*		
Poraver® 0.25-0.5 mm	A_1: 30	7.5	0.55	$W_{OD,1}$: 6.4	$W_{SSD,1}$: 8.32	*6.24*	$W_{stk,1}$: 6.88
Poraver® 0.1-0.3 mm	A_2: 35	8.8	0.89	$W_{OD,2}$: 36.3	$W_{SSD,2}$: 49.0	*0.88*	$W_{stk,2}$: 39.49
3M™ K-1	A_3: 22	12.94	0.52	$W_{OD,3}$: 48.10	$W_{SSD,3}$: 58.68	*1.81*	$W_{stk,3}$: 54.32

ADMIXTURES

Admixture	*lb/gal*	*Dosage (fl.oz/cwt)*	*% Solids*	*Water in Admixture (lb/yd³)*	
Xypex® Xycrylic	*8.8*	x_1: 26.85	s_1: 72.0	$w_{admx,1}$: *8.26*	*Total Water from All Admixtures* ___*9.73*__ *lb/yd³*
BASF Glenium® 3030NS	*9.2*	x_2: 6.34	s_2: 79.7	$w_{admx,2}$: *1.47*	

SOLIDS (LATEX, DYES AND POWDERED ADMIXTURES)

Component	*Specific Gravity*	*Volume (ft³)*	*Amount (mass/volume) (lb/yd³)*
Xypex® Xycrylic	**1.05**	**0.32**	S_1:21.21

WATER

	Amount (mass/volume) (lb/yd³)		*Volume (ft³)*
Water, lb/yd³		w:798	*12.79*
Total Free Water from All Aggregates, lb/yd³		$\sum w_{free}$:-15.31	
Total Water from All Admixtures, lb/yd³		$\sum w_{admx}$: 9.7	
Batch Water, lb/yd³		w_{batch}:803.58	

DENSITIES, AIR CONTENT, RATIOS AND SLUMP

	cm	*fibers*	*aggregates*	*solids*	*water*	*Total*
Mass of Concrete, M, (lb, for1 yd³)	1596	0	116.0	21.21	803.58	*M:2536.8*
Absolute Volume of Concrete, V, (ft³)	9.39	*0*	*2.93*	*0.32*	*12.79*	*V:25.43*
Theoretical Density, T, (= M / V)	99.7	*lb/ft³*	***Air Content [= (T – D)/D x 100%]***			*8.29 %*
Measured Density, D	92.1	*lb/ft³*	***Slump, Slump flow***			*1 in.*
water/cement ratio, w/c:	1.0		***water/cementitious material ratio, w/cm:***			0.5

Pigmented Finishing Mixture:

CEMENTITIOUS MATERIALS

Component	*Specific Gravity*	*Volume (ft^3)*	*Amount (mass/volume) (lb/yd^3)*		
Federal White Type I Portland Cement	3.15	4.06	*c:*	*798*	*Mass of all cementitious materials, cm* ***___1596____*** *lb/yd^3*
Class C Fly Ash	2.4	5.33	m_1:	*798*	*c/cm ratio* ***0.5***

FIBERS

Component	*Specific Gravity*	*Volume (ft^3)*	*Amount (mass/volume) (lb/yd^3)*	
N/A				

AGGREGATES

Aggregates	*Abs (%)*	*MC_{stk} (%)*	*SG*	*Base Quantity (lb/yd^3)*		*Volume, SSD (ft^3)*	*Batch Quantity (at MC_{stk}) (lb/yd^3)*
				OD	*SSD*		
Poraver® 0.25-0.5 mm	A_1: 30	7.5	0.55	$W_{OD,1}$: 6.4	$W_{SSD,1}$: 8.32	*6.24*	$W_{stk,1}$: 6.88
Poraver® 0.1-0.3 mm	A_2: 35	8.8	0.89	$W_{OD,2}$: 36.3	$W_{SSD,2}$: 49.0	*0.88*	$W_{stk,2}$: 39.49
3M™ K-1	A_3: 22	12.94	0.52	$W_{OD,3}$: 48.10	$W_{SSD,3}$: 58.68	*1.81*	$W_{stk,3}$: 54.32

ADMIXTURES

Admixture	*lb/gal*	*Dosage (fl.oz/cwt)*	*% Solids*	*Water in Admixture (lb/yd^3)*	
Xypex® Xycrylic	*8.8*	x_1: 26.85	s_1: 72.0	$w_{admx,1}$: *8.26*	*Total Water from All Admixtures* ***___9.73__*** *lb/yd^3*
BASF Glenium® 3030NS	*9.2*	x_2: 6.34	s_2: 79.7	$w_{admx,2}$: *1.47*	

SOLIDS (LATEX, DYES AND POWDERED ADMIXTURES)

Component	*Specific Gravity*	*Volume (ft^3)*	*Amount (mass/volume) (lb/yd^3)*
Xypex® Xycrylic	**1.05**	**0.32**	S_1: 21.21
Pigments – Various Colors	**2.25**	**0.11**	S_2: 15.00

WATER

	Amount (mass/volume) (lb/yd^3)		*Volume (ft^3)*
Water, lb/yd^3		w:798	*12.79*
Total Free Water from All Aggregates, lb/yd^3		$\sum w_{free}$:-15.31	
Total Water from All Admixtures, lb/yd^3		$\sum w_{admx}$: *9.7*	
Batch Water, lb/yd^3		w_{batch}:803.58	

DENSITIES, AIR CONTENT, RATIOS AND SLUMP

	cm	*fibers*	*aggregates*	*solids*	*water*	*Total*
Mass of Concrete, M, (lb, for1 yd^3)	1596	0	116.0	36.21	803.58	*M:2551.79*
Absolute Volume of Concrete, V, (ft^3)	9.39	*0*	*2.93*	*0.43*	*12.79*	*V:25.54*
Theoretical Density, T, (= M / V)	99.7	*lb/ft^3*	***Air Content [= (T – D)/D x 100%]***			*8.29 %*
Measured Density, D	92.1	*lb/ft^3*	***Slump, Slump flow***			1 *in.*
water/cement ratio, w/c:	1.0		***water/cementitious material ratio, w/cm:***			0.5

Inlay/Outlay Mixture:

CEMENTITIOUS MATERIALS

Component	*Specific Gravity*	*Volume (ft^3)*	*Amount (mass/volume) (lb/yd^3)*		
Federal White Type I Portland Cement	3.15	1.76	*c:*	*345*	*Mass of all cementitious materials, cm* ___*690*___ *lb/yd^3*
Class C Fly Ash	2.4	2.30	m_1:	*345*	*c/cm ratio* ___*0.5*___

FIBERS

Component	*Specific Gravity*	*Volume (ft^3)*	*Amount (mass/volume) (lb/yd^3)*	
Nycon-PVA RECS15	1.3	0.105	f_1:	*17*

AGGREGATES

Aggregates	*Abs (%)*	*MC$_{stk}$ (%)*	*SG*	*Base Quantity (lb/yd^3)*		*Volume, SSD (ft^3)*	*Batch Quantity (at MC$_{stk}$) (lb/yd^3)*
				OD	*SSD*		
Poraver ® 1-2 mm	A_1: 20	5.86	0.51	$W_{OD,1}$: 178.90	$W_{SSD,1}$: 214.68	*6.75*	$W_{stk,1}$: 189.38
Poraver® 0.5-1.0 mm	A_2: 25	5.24	0.53	$W_{OD,2}$: 99.3	$W_{SSD,2}$: 124.13	*3.75*	$W_{stk,2}$: 104.50
Poraver® 0.25-0.5 mm	A_3: 30	7.5	0.55	$W_{OD,3}$: 45.3	$W_{SSD,3}$: 58.9	*1.72*	$W_{stk,3}$: 48.70
3M™ K-1	A_4: 22	12.94	0.52	$W_{OD,4}$: 35.90	$W_{SSD,4}$: 43.80	*1.35*	$W_{stk,4}$: 40.55

ADMIXTURES

Admixture	*lb/gal*	*Dosage (fl.oz/cwt)*	*% Solids*	*Water in Admixture (lb/yd^3)*	
Xypex® Xycrylic	*8.8*	x_1: 35.29	s_1: 72.0	$w_{admx,1}$: *4.69*	*Total Water from All Admixtures* ___*5.33*___ *lb/yd^3*
BASF Glenium® 3030NS	*9.2*	x_2: 6.34	s_2: 79.7	$w_{admx,2}$: *0.64*	

SOLIDS (LATEX, DYES AND POWDERED ADMIXTURES)

Component	*Specific Gravity*	*Volume (ft^3)*	*Amount (mass/volume) (lb/yd^3)*
Xypex® Xycrylic	**1.05**	**0.18**	S_1:12.05

WATER

	Amount (mass/volume) (lb/yd^3)		*Volume (ft^3)*
Water, lb/yd^3		*w*:345	*5.33*
Total Free Water from All Aggregates, lb/yd^3		$\sum w_{free}$:-58.36	
Total Water from All Admixtures, lb/yd^3		$\sum w_{admx}$: *5.3*	
Batch Water, lb/yd^3		w_{batch}:398.0	

DENSITIES, AIR CONTENT, RATIOS AND SLUMP

	cm	*fibers*	*aggregates*	*solids*	*water*	*Total*
Mass of Concrete, M, (lb, for1 yd^3)	690	17	441.5	12.05	398.04	*M:1558.58*
Absolute Volume of Concrete, V, (ft^3)	4.06	*0.21*	*13.62*	*0.18*	*5.53*	*V:23.55*
Theoretical Density, T, (= M / V)	66.2	*lb/ft^3*	***Air Content [= (T – D)/D x 100%]***			*12.96* %
Measured Density, D	58.6	*lb/ft^3*	***Slump, Slump flow***			0.5 *in.*
water/cement ratio, w/c:	1.0		***water/cementitious material ratio, w/cm:***			0.5

Appendix C: Sample Calculations

Appendix C - Struc Calcs | MTU Concrete Canoe 2016 | 1/3

Analysis of mid-section of a canoe for a 4 person co-ed

Assumptions

Women's Paddler Load

170 lb with 20% increase due to dynamic loading

$1.2(170\text{lb}) = 204\text{ lb}$

Men's Paddler Load

200 lb with 20% increase due to dynamic loading

$1.2(200\text{lb}) = 240\text{ lb}$

Loading Case (From bow to stern)

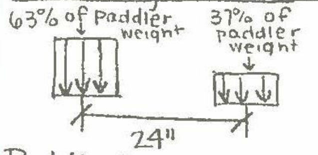
① Male paddler – sitting = 240lb = P_{BM}

② Female Paddler – kneeling = 204lb = P_{BF}

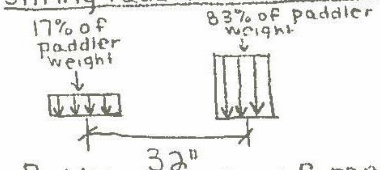
③ Female Paddler – kneeling = 204lb = P_{SF}

④ Male Paddler – kneeling = 240lb = P_{SM}

Kneeling Paddler (each line load 6" long)



Sitting Paddler (each line load 6" long)



Paddler 2: center of mass @ 72" from bow

Paddler 3: center of mass @ 161" from bow

Paddler 4: center of mass @ 195" from bow

Paddler 1: center of mass @ 48" from bow

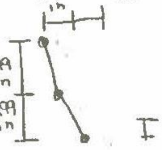
- Nominal thickness = 3/8", unit weight concrete = 57 pcf
- Canoe is free to pitch in water
- X and y coordinates reference same axis set used by PROLINES

Cross Sectional Properties (needed to find canoe self weight + bouyant forces)

- 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 114 inches from the bow, which is the midpoint of the canoe. Cross Section 114 has 72 control points. Properties were calculated for one side, and doubled if necessary

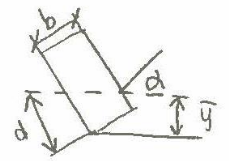
Control Points

Point	x(in)	y(in)
1	−14.25	5.4037
2	−14.10	4.4126
3	−13.94	3.4230



gunwale y location = 5.404 in

keel y location = −9.660 in



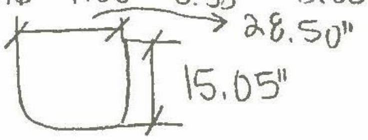
$$I = \frac{bd}{12}\left(d^2\cos^2\alpha + b^2\sin^2\alpha\right)$$
$$A = b\cdot d$$
$$\bar{y} = \tfrac{1}{2}\left(d\cos\alpha + b\sin\alpha\right)$$

From Engineer's Edge www.engineersedge.com/calculators/section_square_case_9.htm

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

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	0.15	−0.99	0.15	1.00	0.38	0.03	0.52	4.94
2	0.16	−0.99	0.16	1.00	0.38	0.03	0.52	3.95

Cross Section 114" dimensions



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

Area, A: Sum of all areas, multiplying by two $\Rightarrow A = 18.09 \text{ in}^2$

Location of neutral axis, $\bar{y}$ using A and centroids, location of neutral axis can be found: $\bar{y} = \frac{\Sigma(Ac)}{\Sigma A} = -2.25$ in

Ix: Given I_c, A, $\bar{y}$ and location of neutral axis, Ix about the x axis can be found using parallel axis theorem.

$$I_x = \Sigma I + \Sigma(ad^2) = 775.09 \text{ in}^4$$

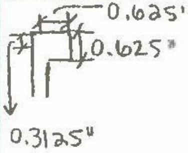
Gaps and Overlaps

- 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 114":

$A_{gap} = -1.02 \text{ in}^2$ $\bar{y}$ from coor axis $= -3.53$ in Ix about x-axis $= -5.20 \text{ in}^4$

Gunwale Caps



$A_{cap} = 0.78 \text{ in}^2$

$\bar{y}$ from coor. axis $= 5.0912$ in

Ix about axis $= 20.28 \text{ in}^4$

Total Cross Section Properties (adding together appropriately)

$A = 17.85 \text{ in}^2$

$\bar{y} = -1.85$ in

$I_x = 790.16 \text{ in}^4$ I about neutral axis $= 733.75 \text{ in}^4$

Loading

Paddler 1 - male sitting

Sitter front line load: $(200\text{lb})(1.2) \cdot 0.17/6\text{in} = 6.8 \text{ lb/in}$ starts @ 18 in from bow

Sitter rear line load: $(200\text{lb})(1.2) \cdot 0.17/6\text{in} = 33.2 \text{ lb/ft}$ starts @ 50 in from bow

Paddler 2 - female kneeling

Kneeler front line load: $(170\text{lb})(1.2) \cdot 0.63/6\text{in} = 21.4 \text{ lb/in}$ starts @ 60 in from bow

Kneeler rear line load: $(170\text{lb})(1.2) \cdot 0.37/6\text{in} = 12.6 \text{ lb/in}$ starts @ 84 in from bow

Paddler 3 - female kneeling

Kneeler front line load: $(170\text{lb})(1.2) \cdot 0.63/6\text{in} = 21.4 \text{ lb/in}$ starts @ 149 in from bow

Kneeler rear line load: $(170\text{lb})(1.2) \cdot 0.37/6\text{in} = 12.6 \text{ lb/in}$ starts @ 173 in from bow

Paddler 4 - male kneeling

Kneeler front line load: $(200\text{lb})(1.2)(0.63/6\text{in}) = 25.2 \text{ lb/in}$ starts @ 183 in from bow

Kneeler rear line load: $(200\text{lb})(1.2)(0.37/6\text{in}) = 14.8 \text{ lb/in}$ starts @ 207 in from bow

Canoe Self Weight

Self weight was determined using an assumed concrete weight of 57 pcf and the volume of each cross-sectional areas and distances from the bow.

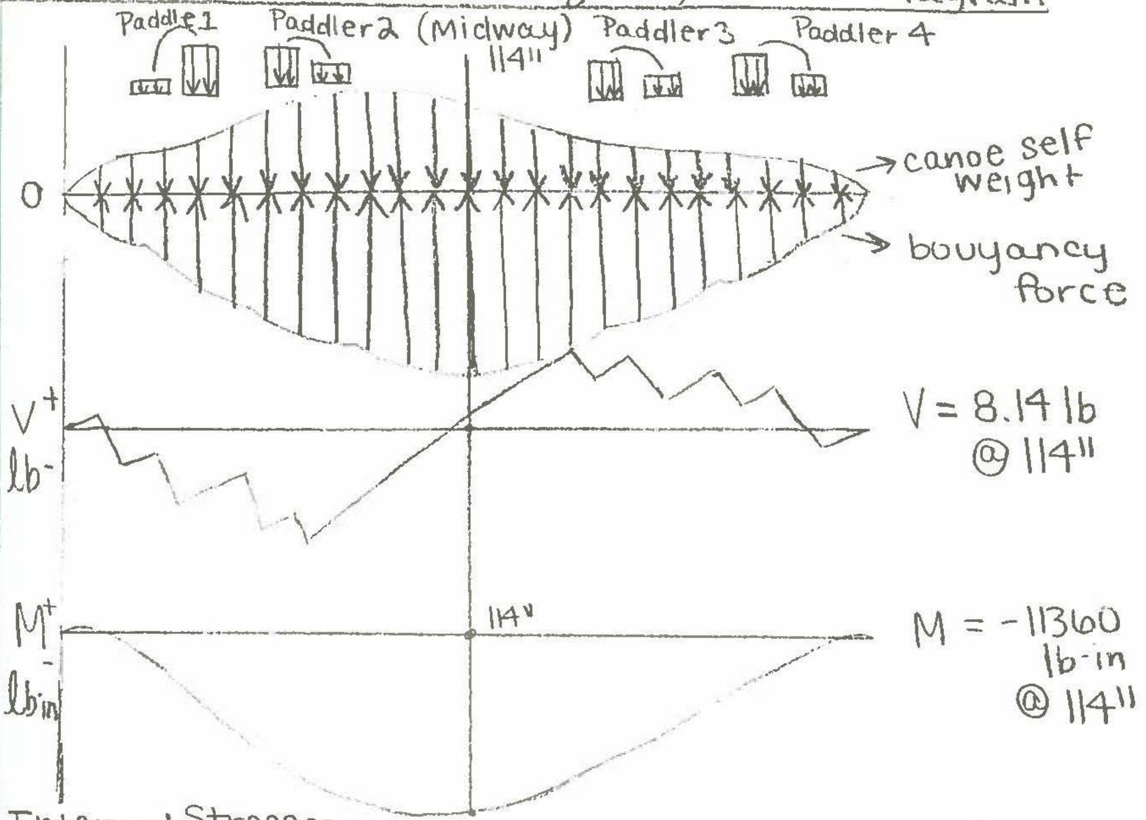
C.G. = 113.862 in CW = 109.80 lbs

Buoyant Force

Buoyant force is the force needed to counteract the paddler load and canoe weight acts through the center of buoyancy. By raising the bow or stern, the center of buoyancy shifts. During the calculation of cross-sectional properties, the volume of the cross-section submerged as the water load increased in 0.01 inch increments were recorded in a 1001 x 227 matrix. Using these values, a baseline waterline was set at the C.G. based on the water depth that created a buoyant force that would counteract the paddler and canoe load. The canoe was then rotated to raise or lower the bow. The new volume and C.B. were recorded. This process was iterated until the following static equilibrium was met.

$$\circlearrowleft^{+}\sum M_{bow} = 0 = -P_{BM}\cdot D_{PBM} - P_{BF}\cdot D_{PBF} - P_{SF}\cdot D_{PSF} - P_{SM}\cdot D_{PSM} - Cw\cdot C.G. - CB\cdot \text{Bouyant}$$

Loading Diagram, Shear Diagram, Moment Diagram



Internal Stresses

$\sigma = \frac{My}{I}$ $\quad y_{gunwale} = 5.404\,in - (-1.85\,in) = 7.25\,in$

$\quad y_{keel} = -9.660\,in - (-1.85\,in) = -7.81\,in$

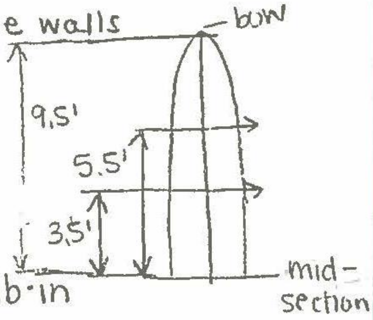
$\sigma_{gunwale} = -11360\,in\text{-}lb\left(\frac{7.254\,in}{733.75\,in^4}\right) = -112\,psi$

$\sigma_{keel} = -11360\,in\text{-}lb\left(\frac{-7.810\,in}{733.75\,in^4}\right) = 121\,psi$

Transverse Loading Case

Assumptions

74.6% of paddler weight is being applied to the walls



$Weight_{male} = 200lb(74.6\%) = 149.2\,lb$

$Weight_{female} = 170lb(74.6\%) = 126.8\,lb$

$M_{male} = 149.2lb(5.5ft)\left(\frac{12in}{1ft}\right) = 9.8(10^3)\,lb\cdot in$

$M_{female} = 126.8\,lb(3.5ft)\left(\frac{12in}{1ft}\right) = 5.3(10^3 lb\cdot in$

$Total\ M = M_{male} + M_{female}$

$Total\ M = 9.8(10^3)\,lb\cdot in + 5.3(10^3)\,lb\cdot in = 1.5(10^4)\,lb\cdot in$