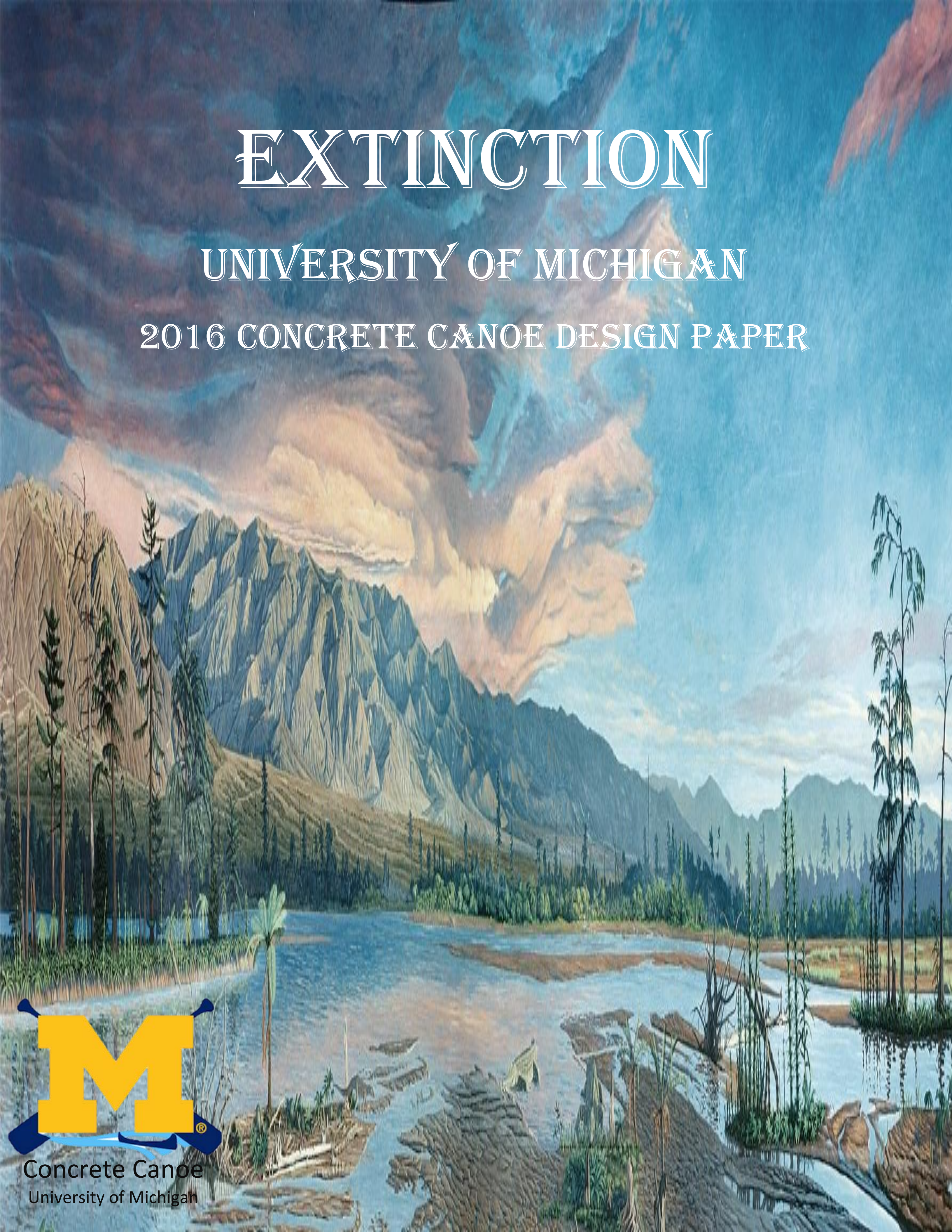
EXTINCTION

UNIVERSITY OF MICHIGAN

2016 CONCRETE CANOE DESIGN PAPER



Concrete Canoe
University of Michigan

TABLE OF CONTENTS	

LIST OF TABLES	

LIST OF FIGURES	

EXECUTIVE SUMMARY

The University of Michigan located in Ann Arbor, has been known for its commitment to research since its founding in 1817. As a research institution, the University of Michigan has prided itself on using new methods to study the historic artifacts. This cultivation is evidenced by the 25 diverse, student-run design teams in the College of Engineering. As one of these design teams, the Michigan Concrete Canoe Team (MCCT) operates in the Wilson Student Project Team Center, which provides the necessary resources and opportunities for success. This year, MCCT utilized new techniques to rediscover past methods to create a complete canoe. The name *EXTINCTION* was selected for the 2016 canoe in hopes that our team continues make historic canoes so that innovation does not disappear.

At the 2015 North Central Regional competition hosted by University of Toledo, the canoe *ALLEGRO* finished with an overall placement of second place. Previously, the 2014 canoe *LEGACY* placed third overall, and the 2013 canoe *DREKAR* placed sixth overall.

Comprising of largely underclassmen, MCCT implemented many new idea in the creation of *EXTINCTION*. A prototype of our hull design was built in order to test the hydrodynamic performance before the construction of the concrete version. The keel was lowered near the bow and stern of the canoe to increase turning resistance. The mold reverted back to the male mold for possible design aesthetics and budgetary reasons.

With the removal of stain from this year's canoe, the team experimented with pigments and vinyl lettering. Although pigmented concrete was cut in our final aesthetic decision, vinyl lettering improves the overall look of our canoe.

To preserve the knowledge from the upper classmen for future year, each of the technical leads took on an apprentice. Paddlers also had more rigorous instruction on turns and correctional strokes. With our efforts, the impact of the departure of the upperclassmen would not be devastating.

In the hopes that it will be as historic as its name, the Michigan Concrete Canoe Team presents the 2016 canoe, *EXTINCTION*.

Table 1: *EXTINCTION* Specifications

EXTINCTION	
Weight	250 pounds
Length	20 feet
Width	30 inches
Depth	15.3 inches
Average Hull Thickness	1 inch
Concrete Colors	Gray
Concrete Unit Weight	58 lb/ft^3 (dry) 58.8 lb/ft^3 (wet)
Compressive Strength	1150 psi
Split Tensile Strength	330 psi
Flexural Strength	370 psi
Air Content	5.8%
Reinforcement	Fiberglass mesh

PROJECT MANAGEMENT

The goal for MCCT this year was to maintain the growth of the team, starting with the inclusion of younger members. As a result, a heavy focus was placed on recruiting and training new members to ensure that a variety of talent would be available for years to come.

The 2015-2016 project schedule was planned to follow the outline set forth by the 2015 canoe, *ALLEGRO*. Critical path events were laid out at the beginning of the year as follows: mass meeting, finalize hull design, finalize mix selection, placement of canoe, completion of sanding, and finishing of canoe. Milestone activities were then identified for each critical path event, which dictated the work schedule for the year. To ensure a flexible critical path, critical path events were reevaluated at the beginning of each semester. Similar to that of *ALLEGRO*, the placement date of *EXTINCTION* was set in December to eliminate the interference of the curing process with the sanding process. However, due to poor quality control, the canoe had unfavorable conditions that MCCT was not confident to compete. This led to a revised critical path for the placement of canoe, completion of sanding, and finishing of the canoe.

The following milestone activities were selected to ensure the completion of the critical path events: recruit new members, reach out for sponsorship, mix and test concrete sample batches, design hull, cut and assemble mold, place canoe, sand and de-mold, stain and seal, and create display and stands. The captain gave out different responsibilities to the experienced members and leads to ensure the timely completion of milestone tasks.

Quality control and assurance for all construction and design processes were achieved through supervision by experienced members, thorough teaching of new members of theory behind design, and training of proper use of facilities and programs.

Safety standards were met using guidelines from ASTM and University of Michigan Facility usage. All members were required to complete training for respirator, project area, and concrete lab usage. Experienced members enforced proper conduct and safety procedures during all meetings

This year's project was divided into four main categories and total person-hours were tracked for each, as shown in Table 1 below. Due to the improper placement of the canoe, an emphasis was placed on the construction of *EXTINCTION*.

Table 2: Division of project man hours.

Task	Hours
Research and Development of Concrete Materials	180
Recruitment and Resource Acquisition	150
Hull Design	180
Construction and Finishing of Canoe and Stands	350

This year, the budget for our canoe was $7945. The majority of this money was allotted to concrete materials, construction materials, competition, paddling practice, and recruitment. Funding was obtained from university departments and student governments, as well as from local businesses. Additional funds were raised by working at various events around campus and participating in fundraising events as a team. A number of concrete materials were also donated. However, this year an unexpected expense to buy a new concrete mixer needed to be included in our budget. Thus this year, we increased fundraising efforts to allow us to stay within our allocated budget.

PROJECT MANAGEMENT RESOURCE ALLOCATION

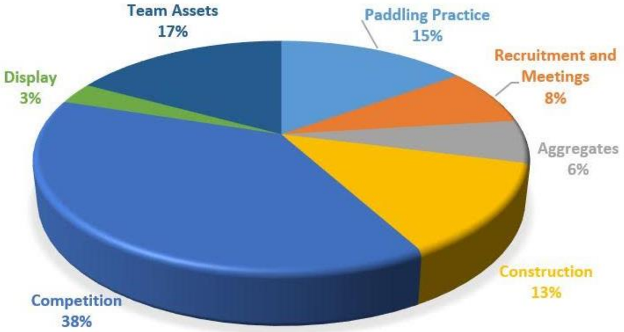


Figure 1: 2015-2016 budget allocations for *EXTINCTION*. Total allotment was $7945. This year the team needs to purchase a new mixer, thus unnecessary spending must be limited. The elimination of stain also reduced our budget significantly.

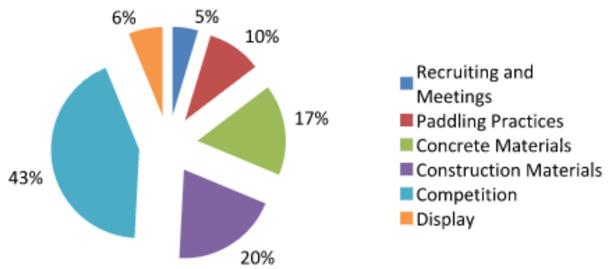


Figure 2: 2014-2015 budget allocations for *ALLEGRO*. Total allotment was $8200. ALLEGRO was our most costly canoe in four years.

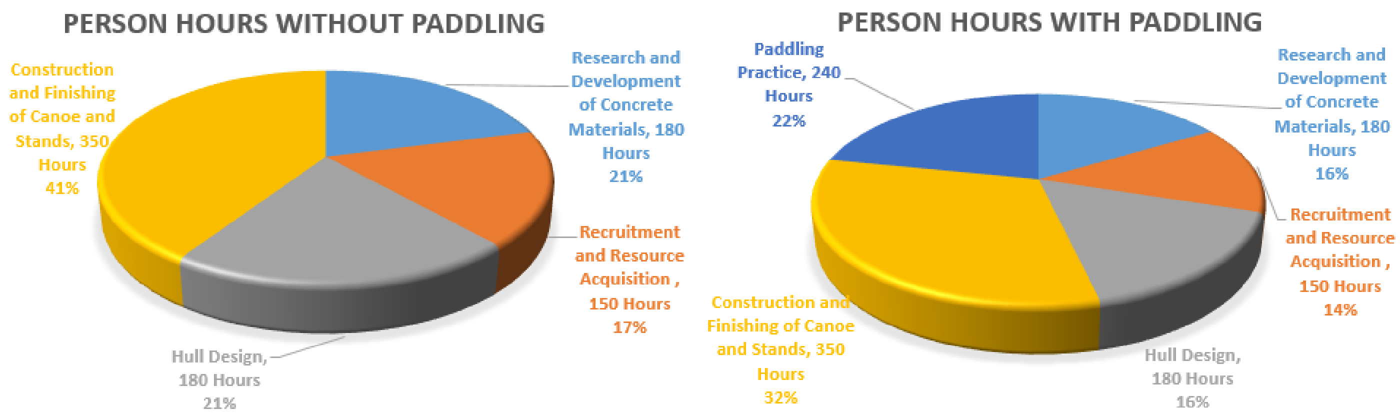
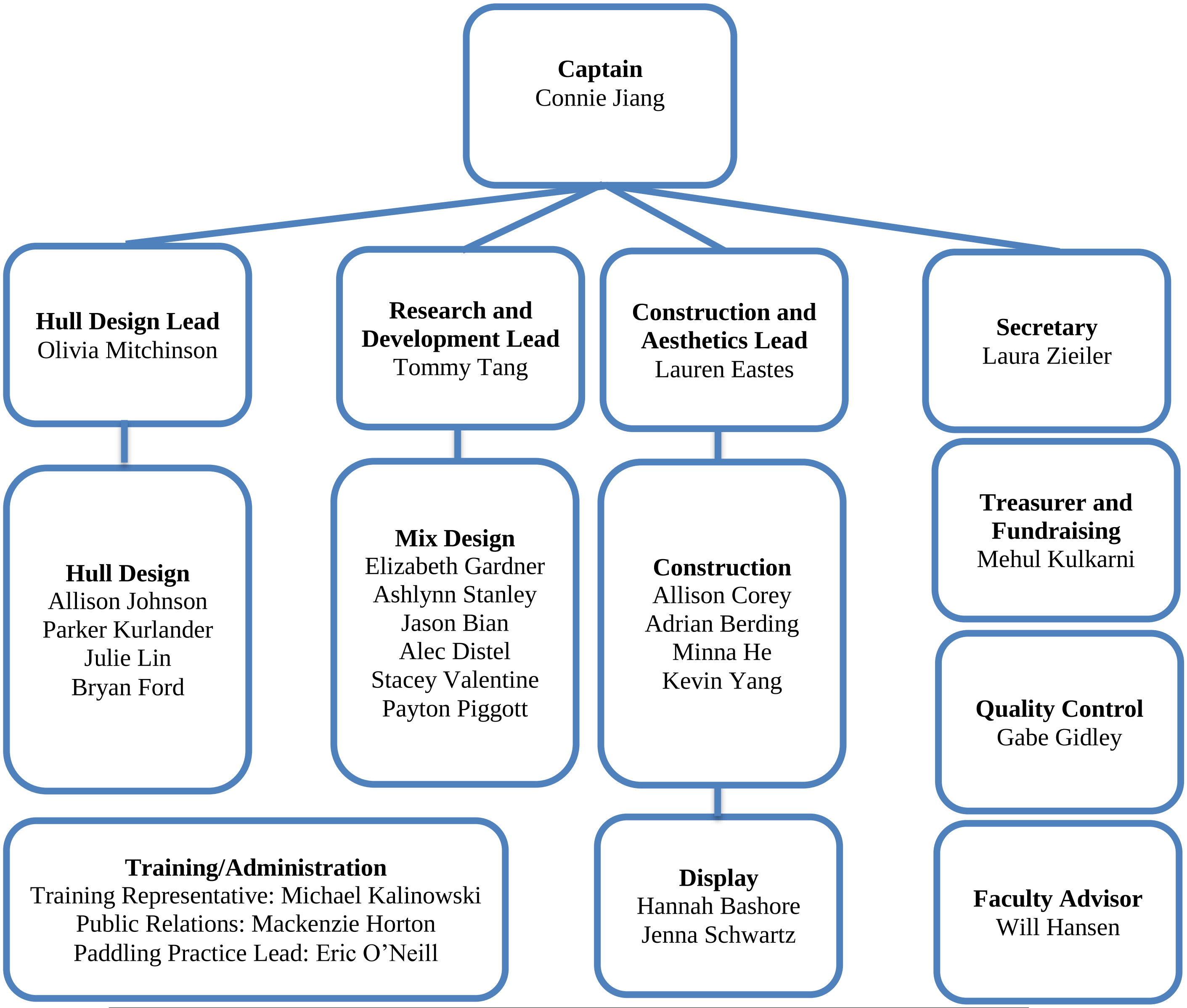


Figure 3: Comparison of person hours with and without paddling. Due to placing out canoe twice this year, the construction and finishing of *EXTINCTION* accounted for greatest portion of person hours for both paddlers and non-paddlers.

ORGANIZATION CHART



Name	Year		Name	Year		Name	Year
Lauren Eastes	Sr		Hannah Bashore	So		Eric O'Neill	So
Bryan Ford	Sr		Allison Corey	So		Ashlynn Stanley	So
Connie Jiang	Sr		Elizabeth Gardner	So		Adrian Berding	Fr
Tommy Tang	Sr		Mackenzie Horton	So		Jason Bian	Fr
Gabe Gidley	Jr		Allison Johnson	So		Alec Distel	Fr
Julie Lin	Jr		Michael Kalinowski	So		Minna He	Fr
Payton Piggott	Jr		Mehul Kulkarni	So		Jenna Schwartz	Fr
Stacey Valentine	Jr		Parker Kurlander	So		Kevin Yang	Fr
Laura Zeiler	Jr		Olivia Mitchinson	So			

HULL DESIGN & STRUCTURAL ANALYSIS

This year, the design process of the hull of *EXTINCTION* resembled the process for *ALLEGRO* with the addition of creating a prototype. MCCT paired experienced members with new members in the process to ensure conservation of talent in future years. Focal points of consideration were stability, ease of paddling, maneuverability, and strength.

The keel line, gunwale line, and cross section shape were modified from the standard hull form to obtain *EXTINCTION*'s final hull form.

Unlike previous years, the team actually had the chance to test preliminary hull designs using a wooden prototype. The prototype's design this year was essentially *ALLEGRO*'s hull with an additional two feet. The team made the prototype out of plywood and covered it with resin to make it waterproof. The prototype required sandbags to mimic the weight of a true concrete canoe.

While designing *EXTINCTION*, several considerations were taken into account with respect to tracking in turning. Poor tracking performance from last year's canoe, *ALLEGRO*, led to this becoming an increased focal point. Originally, the team wanted to increase the length of *ALLEGRO*'s hull in order to increase tracking abilities; however, the prototype did not improve tracking. Instead, the design was changed similarly to *LEGACY* in order to increase the surface area under the water. The larger surface area under the water will meet a greater moment due to resistance when the canoe starts to turn.

The cross section was designed with *ALLEGRO* in mind as it was very stable for paddlers. We chose a design that decreased stress and make the construction of the canoe simpler. To maintain stability, a beam of 30 inches was chosen.

This year, the team returned to the use of a male mold for the construction of the canoe. This is to prevent slumping issues on the gunwales that occurred on last year's female mold.

The final cross section design chosen for *EXTINCTION* is shown in Figure 2.

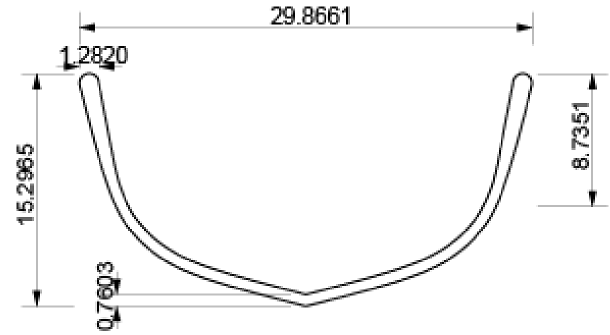


Figure 4: Midship cross section of *EXTINCTION*

The thickness of *ALLEGRO* was 0.75 inches and increased to 1.20 inches along the gunwales. This gradient is done in order to reduce the maximum bending arm by raising the center of area of the cross section and minimize the stress along the gunwale of the canoe when in tension.

To analyze the strength of *EXTINCTION*, seven different load cases were considered. Moments were calculated for the female races, the male races, and the coed race. The tensile stress in the gunwales was calculated using *D*, the maximum distance from the neutral axis, *I*, the moment of inertia, and *M*, the global bending moment. This can be seen in Equation 1.

$$\sigma = \frac{MD}{I} \quad (1)$$

Distributed weight, buoyancy, and point loads were analyzed to find the global bending moment. Maxsurf Stability Suite was used to analyze the difference between buoyant force and distributed weight to calculate tensile strength along the length of the canoe. The maximum value, out of all loading conditions, was found to be 7132.2 lbs-in. Using this value with the stress formula, the maximum tensile force in the gunwale of *ALLEGRO* was calculated to be 66.3 psi. With a concrete tensile strength of 327 psi, the safety factor for this year's design is 4.9.

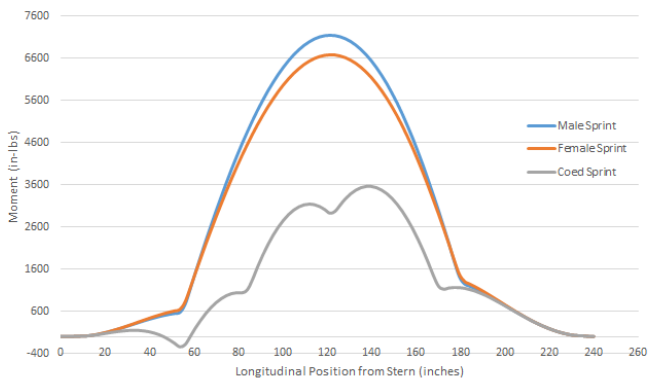


Figure 1: Loading cases for *ALLEGRO*

Additional analysis was completed to deterime resistance. Using the assumption that the hull would be smooth after sanding and sealing the canoe, the frictional resistance coefficient, C_F, was approximated using the skin friction line developed by the International Towing Tank Conference (ITTC 1978).

The skin friction line is defined as Equation 2.

$$C_F = \frac{0.075}{(log_{10}(Re_S)-2)^2} \qquad (2)$$

In equation 2, the length Reynold's number, Re_s, is dependent on the kinematic viscosity, ν, and forward velocity, *V*, which can be seen below in Equation 3.

$$Re_s = \frac{VL}{\nu} \qquad (3)$$

Using the coefficient, C_F ,the frictional resistance, R, can be calculated using Equation 4, where ρ is the density of water and *S* is the wetted surface area.

$$R = C_F \frac{1}{2} \rho S V^2 \qquad (4)$$

Using this approximation, the frictional coefficient component was found to be 0.00353 and the total frictional resistance was calculated to be 1.49 pound-force.

Table 3 below is a summary of the calculations.

Table 3: Resistance Calculation Summary

V	3.38 $\frac{ft}{s}$	C_F	0.00353
L	20 ft	ρ	1.94 $\frac{slug}{ft^3}$
ν	1.664 * 10^{-5} $\frac{ft}{s^2}$	S	38.07 ft^2
Re_s	4.0625 * 10^6	R	1.49 lb

Figure 5: Hull Design of *EXTINCTION*

DEVELOPMENT & TESTING

The success of last year's mix and development procedure led MCCT to focus on designing a slightly stronger mix while maintaining the incredibly low density. In order to design a working mix, the team used a systematic method and used base mixes to hold either cementitious proportions or aggregate gradation constant while freely modifying the other aspects to better understand the properties of cementitious and aggregate materials independent from each other. The final goal was to combine the findings into hybrid mixes that would give the best overall results.

To make the cause of change completely transparent the mix lead utilized a control baseline mix taken from last year's final mix design. The baseline mix was taken down two completely independent paths. One path focused solely on the cementitious proportions while the other focused on the aggregate gradation.

Figure 6: Measuring aggregates and cementitious materials during mixing

The first path used for concrete testing was to systematically alter the cementitious ratios. The cementitious materials used were Portland Cement, Komponent, NewCem Slag Cement (GGBFS), and VCas-160. The team avoided introducing any new cementitious materials this year to remove excess variables and focus on the proportions of the mix. The materials used in years previous were well researched and tested while additional materials would require testing and time that was put to better use elsewhere. Komponent ratio was set at 15% as specified by the manufacturing specifications; this would prevent cracking by minimizing the contraction of concrete while curing. The mix designs that were stronger than the previous year's mix were too dense to be considered as a final mix and ultimately the ratio of cementitious materials in the final mix was the same as the baseline mix.

The other path for the baseline mix was the aggregate gradation. The aggregates that were used this year were K20, Poraver (0.25-0.5, 0.5-1.0, 1.0-2.0), and SG-300. This year, SG-300 replaced the SG-900 that was used last year. Sg-300 has a larger particle size while maintaining a similar density and compressive strength as SG-900. By keeping the cementitious materials constant from the baseline mix, the aggregate gradation was adjusted to see the differences in density and strength. When the gradation was bottom heavy, meaning a higher proportion of smaller aggregates, the strength increased, but the mix sacrificed the low density the team was trying to maintain. The mixes in which a higher proportion of large aggregates were used helped to maintain the low density and fine-tune the strength of the mix.

Figure 7: Mixing different cementitious and aggregate ratios

In the final testing cycle, findings from the cementitious proportion and aggregate testing cycles were combined into hybrid mixes to test the overall effectiveness of each change when interacting with each other. The baseline mix was taken on two independent paths then converged to form a strong, low density final mix.

The baseline mix that was taken from 2015 was tested 9 different times while altering the cementitious materials and holding the aggregates constant and 5 different times while holding cementitious constant and altering the aggregates. Finally 6 hybrid mixes were tested for a total of 20 test-mixes. To ensure consistency amongst mixes, each mix was made, packed in cylinders, and tested for 28-day strength according to ASTM C 109. During all testing, fibers were separated by hand to optimize even distribution throughout the mixes. Grace fibers made of polypropylene were maintained to aid in tensile strength and to prevent cracking in the early curing process. All mixes were packed into 6 and 8 inch cylinders and tested for compressive and tensile strength. After receiving design specifications from the hull design team, the final mix was chosen.

Figure 8: Separating fibers by hand

Figure 9: Packing cylinders for compression and tensile testing

The final mix was a result of aggregate testing and had a density of 58 lb/ft^3 which matched last year's mix. In addition the tensile strength was 327 psi about a 100 psi increase from last year. The compressive strength was 1146 psi about a 30 psi increase.

Figure 10: Compression testing of concrete cylinders

The other mixes tested were either too dense or weak to be considered. When modifying cementitious materials, promising mixes with Komponent ratios below 15% were disregarded due to its manufacturing specifications.

New liquid release agents introduced last year were retested for their release abilities and slump and used in the construction of the final canoe. Huron Technologies Release Coating #7410 and Release Coating #7572 were tested and Release Coating #7410 was chosen after observing the best separation of concrete mixes from foam.

Test mixes of pigmented slurry were also tested. However, the team did not like the look of the pigment slurry, especially after the sanding process. The team decided against using pigments at all this year.

Figure 11: Testing release agents and pigments

The team's goal this year was to continue to investigate the effect of cementitious materials and aggregate gradation independent from each other in order to design a mix that maintained the incredibly low density from last year while increasing the overall strength. This was done by keeping other aspects of the mix consistent such as fibers and liquid addmixtures Glenium 7500 and AE90, a superplasticizer and air entrainer, respectively.

CONSTRUCTION

This year's construction method for *EXTINCTION* followed that of *LEGACY*. Due to the regulations on stain this year, the team originally wanted to add an aesthetic touch by creating irregular-shaped gunwales, specifically teeth-shaped. It was determined that a male mold was better suited for irregular gunwales compared to the female mold, where slumping at the gunwales was an issues during ALLEGRO. The male mold also requires less foam than the female mold, which reduced the impact on the team's budget.

To create the mold, a 3-D model of the canoe was created in Rhinoceros 5.0, which was then partitioned into 72 cross sections of three inch thickness. The cross sections and a flat-bottomed base that had molds for the gunwale and the alignment beams were fitted onto eight 4'x8' sections to be read by a CNC router. The CNC router was used to cut the individual sections from the sheets. To ensure the absolute accuracy of the mold, all sections were cut three-dimensionally to within 1/32 of an inch, using a spherically tipped drill bit.

Figure 12: CNC router cutting sections from foam sheets

The mold was placed on a leveled table, aligned with the three alignment beam and assembled using wood glue. The mold was sanded and spackled to mitigate any imperfections created by the CNC router. Combining the construction methods of *LEGACY* and *ALLEGRO*, the mold was then coated with the liquid release agent the team used last year. The liquid release agent allowed for easier mold removal compared to duct tape.

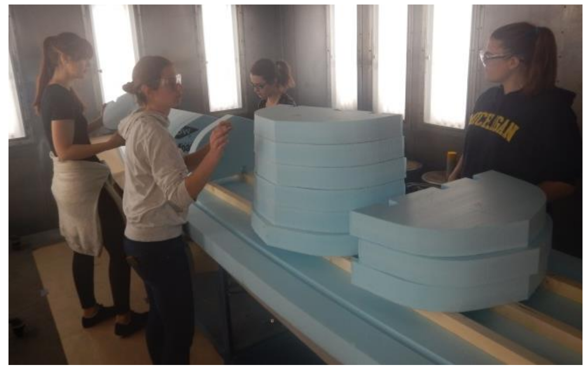


Figure 13: Assembling the mold on the alignment beams

Originally, pour day took place at the end of the fall semester to allow the canoe to cure over the winter break. On pour day, the team was split into three teams: mixing, fiber separation, and concrete placement. The mixing team measured out and mixed 0.3 ft^3 batches of concrete and passed them off to the concrete placement team, who then laid the concrete on the mold. To maintain the constant mixing and placing process, the fiber separation team continuously separated fibers. Since fiber separation has always been a bottleneck in our process, this year the team also separated many batches of fibers before pour day.

The first layer of concrete was 3/8" thick. Next, fiberglass mesh was laid in overlapping 3-foot sections to assist the canoe's tensile strength. Latex was sprayed over the mesh before applying the second layer to improve adhesion between layers. The second layer of concrete started at 3/8" and increased with the gradation to the gunwale. The top layer of concrete was compacted and smoothed using trowels.

Figure 14: Placement of concrete layers

Two people from each concrete placement team were assigned the quality control role. These members used two sizes of quality control devices to ensure consistency of the thickness of the canoe as it was being placed. The devices were made from a nail pushed through a cork with the sharp end of the nail protruding either 3/8" or 3/4". The 3/8" device was used for the first layer and the 3/4" was used for the second. The quality control positions were also tasked continuously towel the gunwale in order to prevent slumping and increasing the thickness.

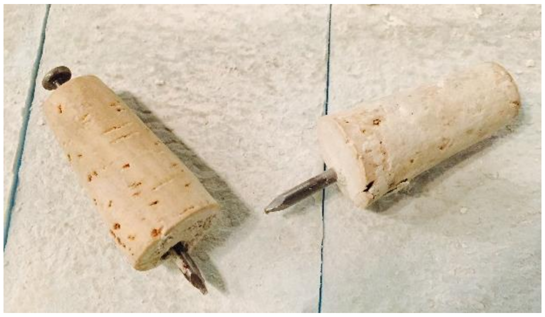


Figure 15: Quality control devices

After pour day, the canoe was wet cured in a temperature controlled room for fourteen days over the winter break. However due to temperature control complication at the Wilson Student Project Team Center, the canoe did not cure properly and resulted in many cracks. The team decided to make an entirely new canoe. Unlike previous years, this would not be detrimental to our schedule as we longer need to stain our canoe. The only drawback was that there is less time for sanding.

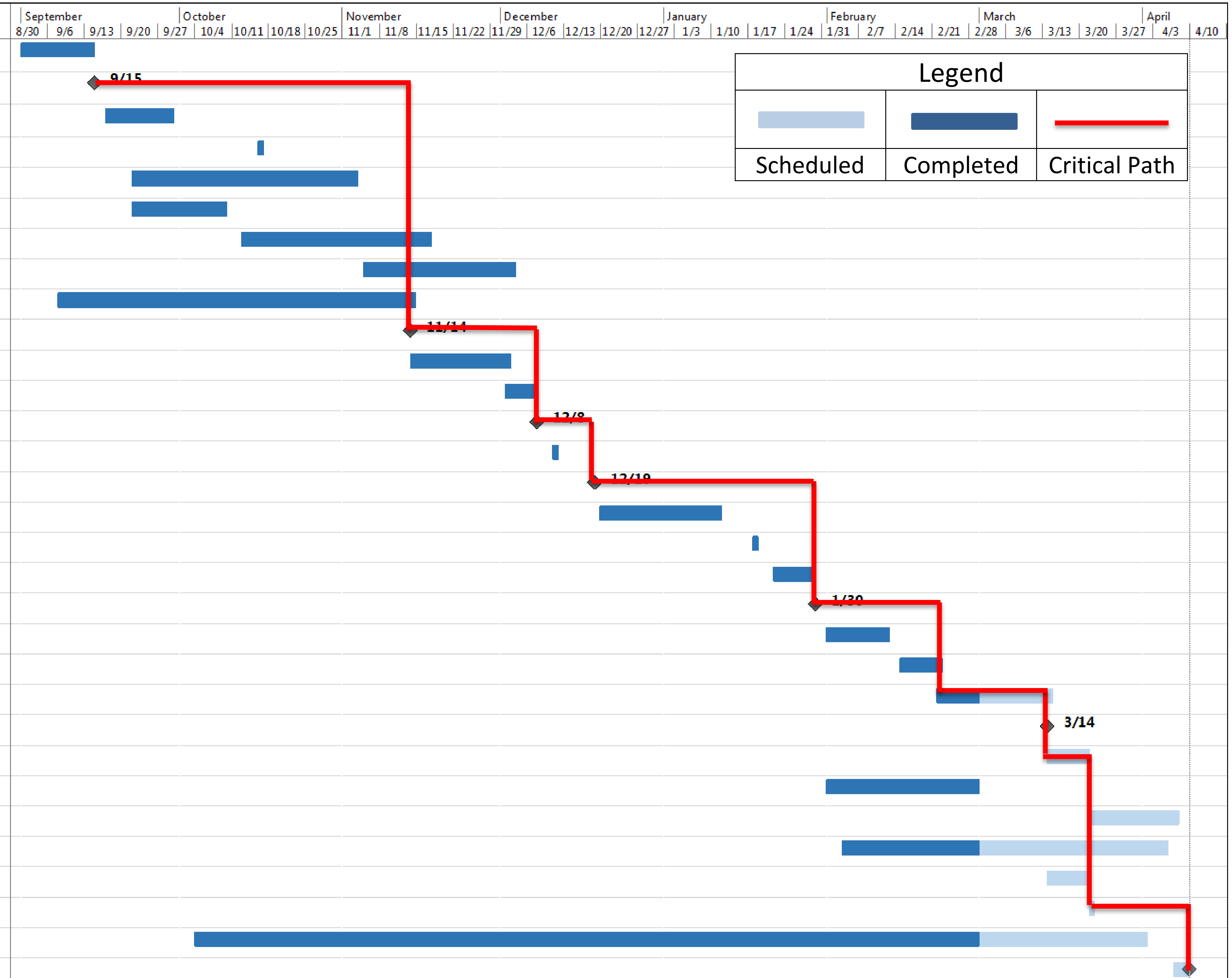
The second pour day progressed much smoother than the first. There was more available manpower to separate fiber and to form a quality control team, a group of people solely focused on hull thickness. However on day 13 of the curing period, the pipe above *EXTICTION* in the Wilson Center broke, cutting the curing process short.

Once cured, the exterior of the canoe was sanded smooth. Hand sanding was primarily used; however, power sanding was used sparingly in areas of large concrete buildup and in interest of time. After the outer hull was deemed smooth enough, *EXTINCTION* was demolded and placed in female mold sections, which were created using the same 3-D modeling and CNC cutting as the mold. The inner hull was then sanded. After the completion of sanding, vinyl adhesive lettering was attached and the canoe sealed. The canoe will be swamp tested to determine whether or not additional flotation will be necessary.

Sustainability was considered a focus for this year's project, which was achieved through selection of cementitious materials and procurement of materials. Leftover materials from previous years were utilized to lower costs of the overall project. Additionally, MCCT worked to purchase materials such as wood and Portland cement from nearby suppliers to reduce environmental effects of shipping and support local businesses. To lower the cost of the team, we continued business with several companies who offered donations to the team. We also received donations from new companies who we will be working with in the future.

PROJECT SCHEDULE

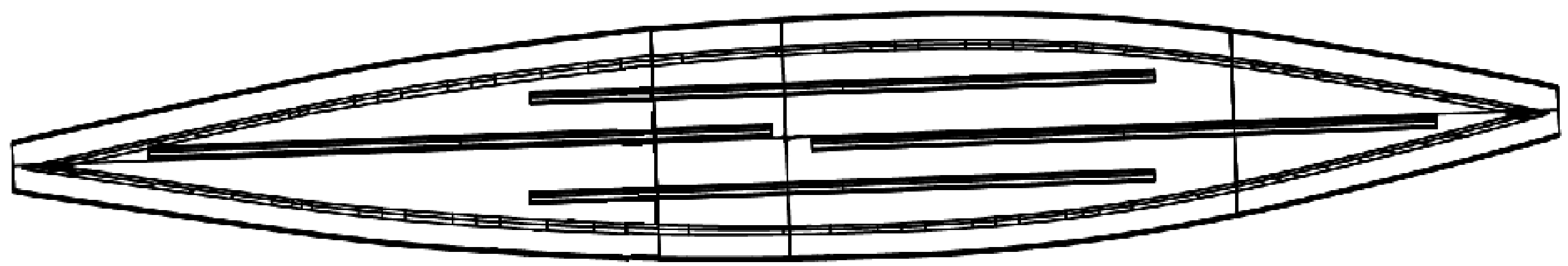
ID	Task Name	Duration	Start
1	New Member Recruitment	14 days	Tue 9/1/15
2	Mass Meeting	0 days	Tue 9/15/15
3	Draft Sponsorship Letters	9 days	Thu 9/17/15
4	Mail Sponsorship Letters	1 day	Fri 10/16/15
5	Determine Theme	31 days	Tue 9/22/15
6	Material Research	14 days	Tue 9/22/15
7	Test Mixing	27 days	Tue 10/13/15
8	Cylinder Testing	22 days	Thu 11/5/15
9	Hull Modeling	50 days	Tue 9/8/15
10	Final Hull Selection	0 days	Sat 11/14/15
11	Arrange Cut Paths	14 days	Sat 11/14/15
12	Mold Cutting	4 days	Wed 12/2/15
13	Final Mix Selection	0 days	Tue 12/8/15
14	Mold Assembly and Preparation	1 day	Fri 12/11/15
15	Place Canoe	0 days	Sat 12/19/15
16	Canoe Curing	17 days?	Sun 12/20/15
17	Canoe Failure	1 day	Mon 1/18/16
18	Mold Assembly and Preparation	6 days	Fri 1/22/16
19	Place Canoe	0 days	Sat 1/30/16
20	Canoe Curing	10 days	Mon 2/1/16
21	Canoe Storage Issues	6 days	Mon 2/15/16
22	Exterior Sanding	16 days	Mon 2/22/16
23	Demold Canoe	0 days	Mon 3/14/16
24	Interior Sanding	6 days	Mon 3/14/16
25	Techincal Paper Writing	21 days	Mon 2/1/16
26	Techincal Presentation Practice	13 days	Tue 3/22/16
27	Design and Construct Display	44 days	Thu 2/4/16
28	Sealing Canoe	6 days	Mon 3/14/16
29	Swamp Test	1 day	Tue 3/22/16
30	Paddling Practice	133 days	Sun 10/4/15
31	Competition	3 days	Thu 4/7/16



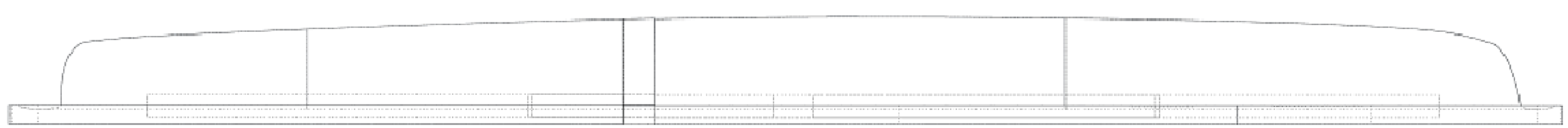
DESIGN DRAWING

MCCT BILL OF MATERIALS

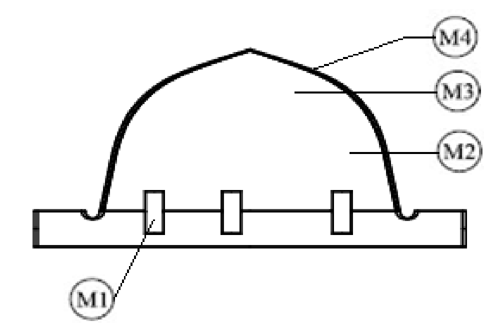
ITEM	QTY	DESCRIPTION
M1	4	LUMBER 2"x4"x8'
M2	8	FOAMBOARD 4'x8'x3"
M3	1	WOOD GLUE
M4	1	RELEASE AGENT



Base View



Side View



NOTES:
3 DIMENSIONAL CROSS SECTIONS OF 3 INCH THICKNESS ARE OBTAINED USING RHINOCEROS 3D AND ARE CUT USING A CNC ROUTER

ALL SECTIONS ARE ALIGNED USING 2X4's' AND GLUES TOGETHER. THE RELEASE AGENT IS APPLIED USING PAINT BRUSHES TO FACILITATE DEMOLDING

MCCT Canoe *Allegro*

VESSEL DESIGNED FOR:
ASCE NCCC

DESIGNED AND DRAWN BY:
MICHIGAN CONCRETE CANOE TEAM

Date: 25 FEB 2016

APPENDIX A: REFERENCES

(1992). "The Reynolds Number: About Rowing and Flying." <http://www.aerodrag.com/Articles/ReynoldsNumber.htm> (Oct. 12, 2013).

(2011). "Canoe Design". < http://www.canoeing.com/canoes/choosing/design.htm> (Oct. 10, 2013).

(2007). "3M Scotchlite Glass Bubbles: K and S series". <http://multimedia.3m.com/mws/mediawebserver?mwsId=SSSSSufSevTsZxtUnxme4Y_9evUqevTSevTSevTSeSSSSSS--&fn=GlassBubbles%20KandS%20Series.pdf> (Sept. 10, 2013).

ACI. (2008). "ACI 318-08 Building Code Requirements for Structural Concrete." American Concrete Institute. Farmington Hills, Michigan.

ASCE/NCCC. (2015). "2015 American Society of Civil Engineers National Concrete Canoe Competition. Rules and Regulations." <http://www.asce.org/uploadedFiles/Membership_and_Communities/Student_Chapters/Concrete_Canoe/Content_Pieces/nccc-rules-and-regulations.pdf> (Feb 12 2015)

ASTM. (2004). "Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens." C496/C496M-11, West Conshohocken, Pennsylvania.

ASTM. (2010). "Standard Specification for Air-Entraining Admixtures for Concrete." C260/C260M-10a, West Conshohocken, Pennsylvania.

ASTM. (2010). "Standard Specification for Fiber-Reinforced Concrete." C1116/C1116M-10a, West Conshohocken, Pennsylvania.

ASTM. (2012). "Standard Practice for Making and Curing Concrete Test Specimens in the Field." C31/C31M-12, West Conshohocken, Pennsylvania.

ASTM. (2012). "Standard Specification for Portland Cement." C150/C150M, West Conshohocken, Pennsylvania.

ASTM. (2014). "Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens." C39/C39M-14a, West Conshohocken, Pennsylvania.

ASTM. (2012). "Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Coarse Aggregate." C127-12, West Conshohocken, Pennsylvania.

ASTM. (2012). "Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Fine Aggregate." C128-12, West Conshohocken, Pennsylvania.

ASTM. (2013). "Standard Specification for Chemical Admixtures for Concrete." C494/C494M-13, West Conshohocken, Pennsylvania.

ASTM. (2013). "Standard Specification for Concrete Aggregates." C33/C33M-13, West Conshohocken, Pennsylvania.

ASTM. (2014). "Standard Specification for Slag Cement for Use in Concrete and Mortars." C989/C989M-14, West Conshohocken, Pennsylvania.

ASTM. (2013). "Standard Test Method for Compressive Strength of Hydraulic Cement Mortars." C109/C109M-13, West Conshohocken, Pennsylvania.

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

Bacon, G. (2005). “Hubble Spots Possible New Moons around Pluto”. <http://www.nasa.gov/vision/universe/solarsystem/hubble_pluto.html> (Jan. 5, 2014).

Cal Poly Concrete Canoe. (2012). “Andromeda.” NCCC Design Paper, California Polytechnic State University, Pomona, California.

(1999). “1978 ITTC Performance Prediction Method.” *International Towing Tank Conference,* Society of Naval Architects and Marine Engineers, Alexandria, Virginia, 1-31.

Michigan Concrete Canoe Team. (2013). “Drekar.” NCCC Design Paper, University of Michigan, Ann Arbor, Michigan.

Michigan Concrete Canoe Team. (2014). “Legacy.” NCCC Design Paper, University of Michigan, Ann Arbor, Michigan.

Michigan Concrete Canoe Team. (2015). “Allegro.” NCCC Design Paper, University of Michigan, Ann Arbor, Michigan.

Raphael, J. M. (1984). “Tensile Strength of Concrete.” < http://www.concrete.org/tempComDocs/1237910-5818/81-17.pdf>. (Nov. 12, 2012).

Slade, Stuart. (1998). “Understanding the Prismatic Coefficient”. <http://www.navweaps.com/index_tech/tech-004.htm>. (Oct. 13, 2012).

University of Nevada Concrete Canoe. (2012). “Ducimus.” NCCC Design Paper, University of Nevada, Reno, Nevada.

APPENDIX B: MIXTURE PROPORTIONS

CEMENTITIOUS MATERIALS				
Component	*Specific Gravity*	*Volume (ft³)*	*Amount (mass/volume) (lb/yd³)*	
Portland Cement Type 1	3.15	1.425	c: 280	Mass of all cementitious materials, cm **700** lb/yd³
GGBFS	2.90	0.580	m_1: 105	
Komponent	3.10	0.543	m_2: 105	
VCAS	2.60	0.129	m_3: 210	c/cm ratio **0.400**

FIBERS			
Component	*Specific Gravity*	*Volume (ft³)*	*Amount (mass/volume) (lb/yd³)*
Grace Fibers	1.30	0.037	f_1: 3.00

AGGREGATES							
Aggregates	*Abs (%)*	*MC_{stk} (%)*	*SG*	*Base Quantity (lb/yd³)*		*Volume, SSD (ft³)*	*Batch Quantity (at MC_{stk}) (lb/yd³)*
				OD	*SSD*		
Poraver 1.0-2.0	A_1: 19	3	0.40	$W_{OD,1}$: 105.00	$W_{SSD,1}$: 124.95	4.207	$W_{stk,1}$: 108.15
Poraver 0.5-1.0	A_2: 18	2	0.50	$W_{OD,2}$: 85.60	$W_{SSD,2}$: 101.01	2.744	$W_{stk,2}$: 87.31
Poraver 0.25-0.5	A_3: 21	4	0.70	$W_{OD,3}$: 81.90	$W_{SSD,3}$: 99.10	1.875	$W_{stk,3}$: 85.176
SG 300	A_4: 1	<1	0.72	$W_{OD,4}$: 94.50	$W_{SSD,4}$: 95.45	2.103	$W_{stk,4}$: 94.50
K20	A_5: 1	<1	0.20	$W_{OD,5}$: 53.00	$W_{SSD,5}$: 53.53	4.247	$W_{stk,5}$: 53.00

ADMIXTURES					
Admixture	*lb/gal*	*Dosage (fl.oz/cwt)*	*% Solids*	*Water in Admixture (lb/yd³)*	
Liquid Latex Modifier	8.8	x_1: 200	s_1: 47	$w_{admx,1}$: 51.01	Total Water from All Admixtures 56.07 lb/yd³
Water Reducer	8.9	x_2: 8.00	s_2: 5	$w_{admx,2}$: 3.70	
Air Entrainer	8.7	x_3: 3.00	s_3: 5	$w_{admx,3}$: 1.36	

SOLIDS (LATEX, DYES AND POWDERED ADMIXTURES)			
Component	*Specific Gravity*	*Volume (ft³)*	*Amount (mass/volume) (lb/yd³)*
Sika Liquid Latex Modifier	1.05	0.78	S_1: 51.01

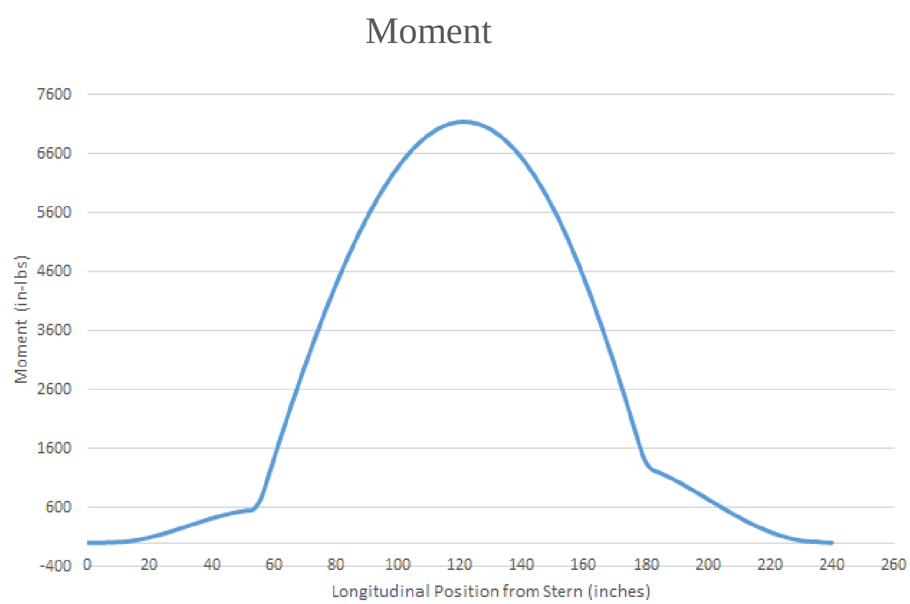
WATER			
	Amount (mass/volume) (lb/yd³)		*Volume (ft³)*
Water, lb/yd³		w: 349.30	5.60
Total Free Water from All Aggregates, lb/yd³		$\sum w_{free}$: 0	
Total Water from All Admixtures, lb/yd³		$\sum w_{admx}$: 56.07	
Batch Water, lb/yd³		w_{batch}: 293.23	

DENSITIES, AIR CONTENT, RATIOS AND SLUMP						
	cm	*fibers*	*aggregates*	*solids*	*water*	*Total*
Mass of Concrete, M, (lb, for 1 yd³)	700	3.00	428.14	51.01	293.23	M: 1475.38
Absolute Volume of Concrete, V, (ft³)	3.84	0.037	15.175	0.78	4.70	V: 24.53
Theoretical Density, T, (= M / V)	61.33	lb/ft³	*Air Content [= (T – D)/D x 100%]*			5.81 %
Measured Density, D	57.76	lb/ft³	*Slump, Slump flow*			4±1 in.
water/cement ratio, w/c:	1.25		*water/cementitious material ratio, w/cm:*			0.499

APPENDIX C: EXAMPLE STRUCTURAL CALCULATION

The calculation for the stress in the male sprint condition was done using the output maximum moment from Maxsurf Stability Suite.

The moment graph was taken from Maxsurf Stability Suite and was used to determine the maximum value for the male loading condition. The maximum value is 7132.2 lb-in.



From the maximum bending moment, the longitudinal position was determined and the cross section was taken at that point. The cross section and the distance for the moment arm can be seen below.

$$\sigma = stress = \frac{M_{max} y}{I}$$

$$M_{max} = max\ bending\ moment = 7132.2\ lb - in$$

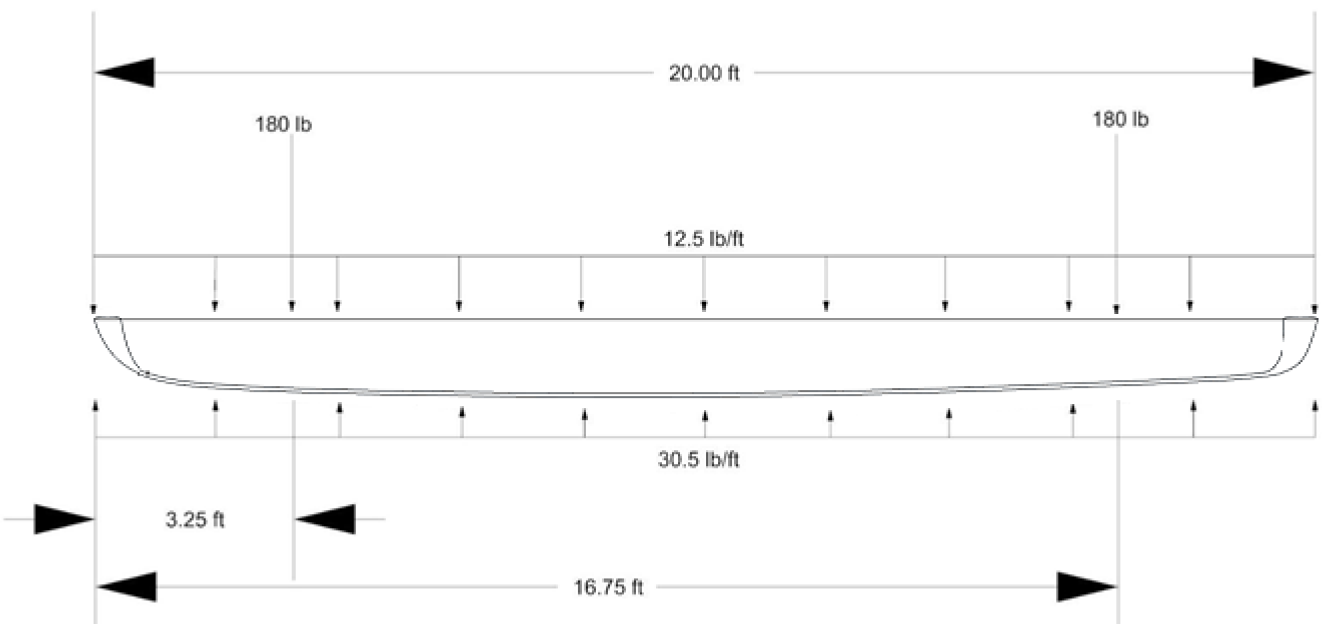
$$y = moment\ arm = 8.87\ in$$

$$I = area\ moment\ of\ inertia\ about\ neutral\ axis = 954.2\ in^4$$

$$\sigma = \frac{7132.2\ lb - in * 8.87\ in}{954.2\ in^4}$$

$$\sigma = \frac{63262.3\ lb - in^2}{954.2\ in^4}$$

$$\sigma = 66.3\ psi$$



Male sprint loading condition