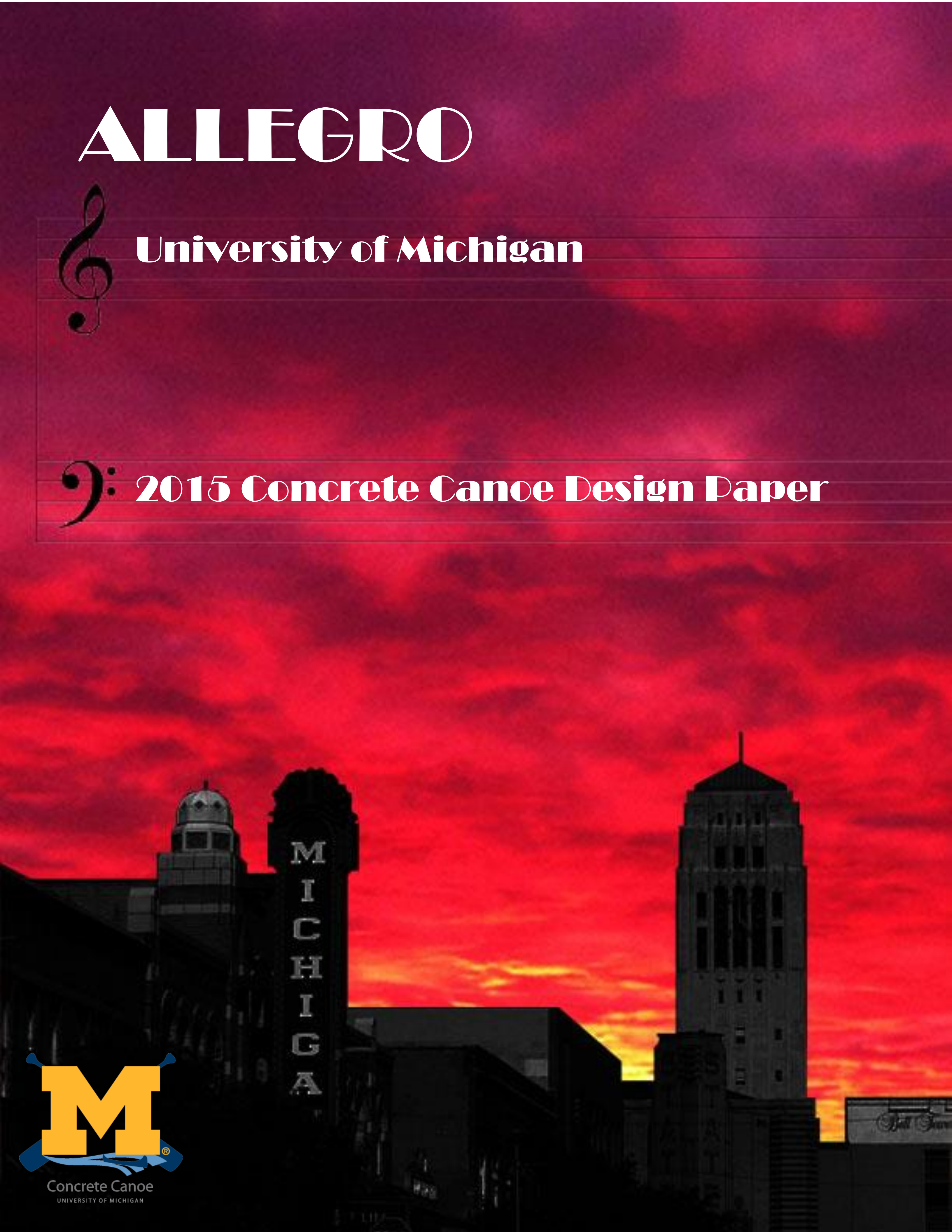
ALLEGRO

University of Michigan

2015 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 promoting unique ideas and challenging old ones much like the founders of jazz. 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. Every year, MCCT combines old ideas with new innovations to compose a fine-tuned canoe. The name, *ALLEGRO*, meaning a lively increase in tempo, was selected for the 2015 canoe to embody the team's upward trajectory and commitment to advancement.

At the 2014 North Central Regional competition hosted by University of Detroit Mercy, the canoe *LEGACY* finished with an overall placement of third place. Previously, the 2013 canoe *DREKAR* placed sixth overall, and the 2012 canoe *CRONUS* placed fourth overall.

Contributions from both returning and new members could potentially make *ALLEGRO* MCCT's most successful canoe to date. Switching from a male mold to a female mold and using a liquid release agent were major innovations in the construction of this year's canoe. The female mold creates a more defined outer hull, which leads to superior performance in the water. The team also altered the hull design by moving the widest point of the canoe aft, which improves tracking. In addition, the keel was raised near the bow and stern of the canoe to lessen turning resistance. The team also switched from a duct tape release agent to a liquid release agent to ease the demolding process.

Formal instruction and practice sessions for paddlers also became a larger priority this year compared to previous years. The canoe name *ALLEGRO* is fitting because the goal of the weekly practice sessions was to improve the team's paddling performance by creating a swifter, more rhythmic paddling technique.

With new introductions such as the female mold and liquid release agent, the team challenged the status quo by breaking free of previous expectations and traditions of the Michigan Concrete Canoe Team.

In the hopes that it will stay true to its name, the Michigan Concrete Canoe Team presents the 2015 canoe, *ALLEGRO*.

Table 1: *ALLEGRO* Specifications

ALLEGRO	
Weight	250 pounds
Length	20 feet
Width	30 inches
Depth	14.75 inches
Average Hull Thickness	1 inch
Concrete Colors	Gray
Concrete Unit Weight	58.70 lb/ft^3 (dry) 59.81 lb/ft^3 (wet)
Compressive Strength	1110 psi
Split Tensile Strength	225 psi
Reinforcement	Fiberglass mesh

Project Management

The goal for MCCT this year was to accelerate the growth and success 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 2014-2015 project schedule closely follows the outline set forth by the 2014 canoe, *LEGACY*. 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, buffers were added between critical path events. Similar to that of *LEGACY*, the placement date of *ALLEGRO* was set in early December to eliminate the interference of the curing process with the sanding process.

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 instability of *LEGACY* during racing, an emphasis was placed on the creation of an innovative hull design for *ALLEGRO*.

Table 2: Division of project person-hours

Task	Hours
Research and Development of Concrete Materials	180
Recruitment and Resource Acquisition	100
Hull Design	150
Construction and Finishing of Canoe and Stands	450

The budget for *ALLEGRO* was $8200; the majority was allotted to concrete materials, construction materials, competition, paddling practice, and recruitment. The breakdown of the budget can be seen in Figure 1. Funding came from donations from local companies for materials and sponsorship from university departments and student governments. Additional funds were acquired by working at the university career fairs as a group. Construction materials exceeded the budget allocations due to the use of a female mold instead of a male mold; however, the budget burden was balanced by increased amounts of donated concrete materials. The estimated cost of the project is $7500, leaving $700 for unexpected expenditures.

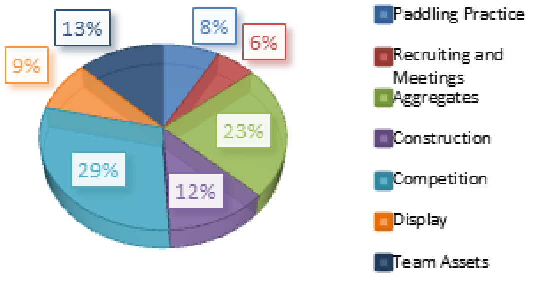
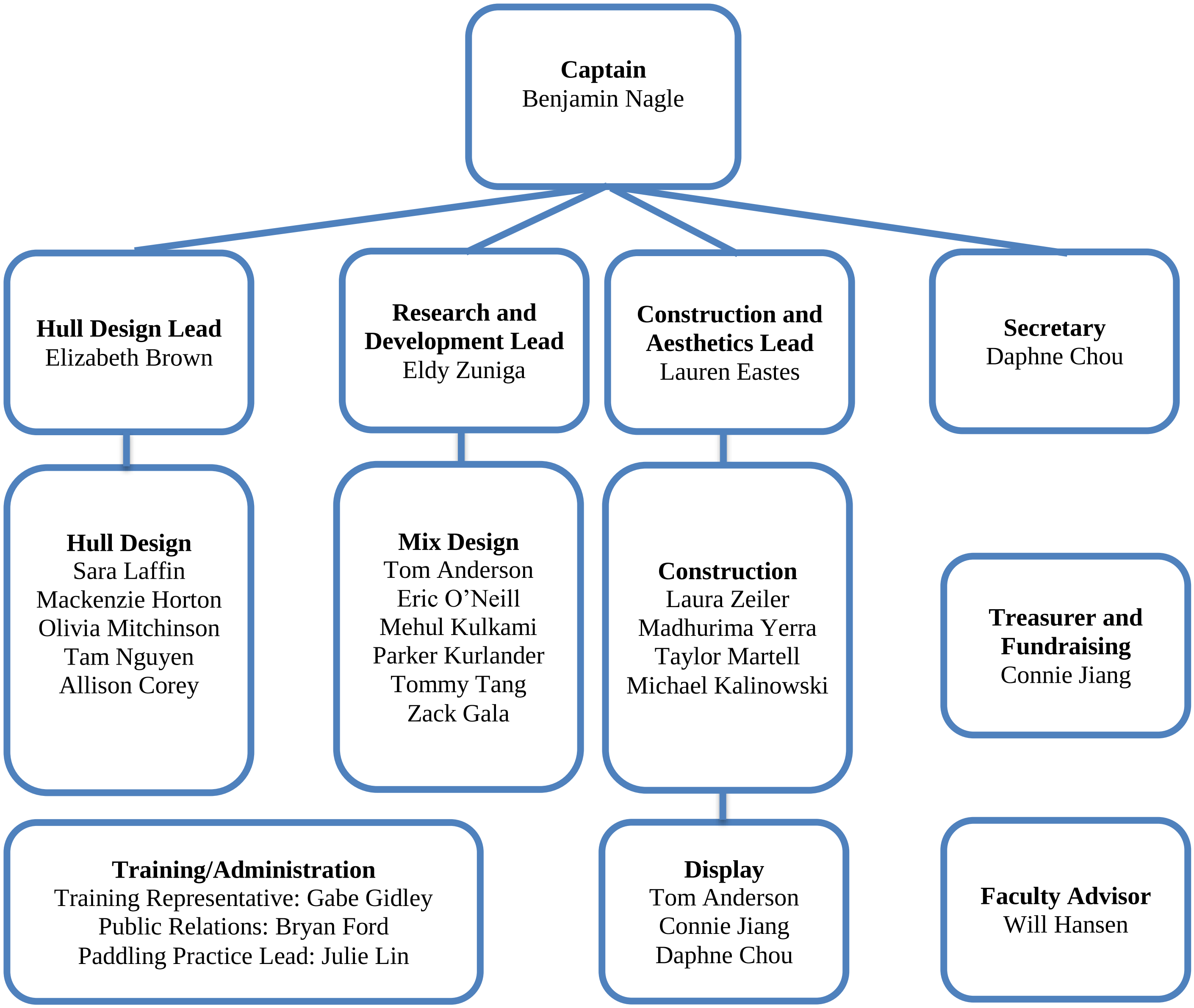


Figure 1: 2014-2015 budget allocations

Organization Chart



Captain
Benjamin Nagle

Hull Design Lead
Elizabeth Brown

Research and Development Lead
Eldy Zuniga

Construction and Aesthetics Lead
Lauren Eastes

Secretary
Daphne Chou

Hull Design
Sara Laffin
Mackenzie Horton
Olivia Mitchinson
Tam Nguyen
Allison Corey

Mix Design
Tom Anderson
Eric O'Neill
Mehul Kulkami
Parker Kurlander
Tommy Tang
Zack Gala

Construction
Laura Zeiler
Madhurima Yerra
Taylor Martell
Michael Kalinowski

Treasurer and Fundraising
Connie Jiang

Training/Administration
Training Representative: Gabe Gidley
Public Relations: Bryan Ford
Paddling Practice Lead: Julie Lin

Display
Tom Anderson
Connie Jiang
Daphne Chou

Faculty Advisor
Will Hansen

Name	Year	Years Attended	Years Registered	Name	Year	Years Attended	Years Registered	Name	Year	Years Attended	Years Registered
Sara Laffin	Grad	3	1	Daphne Chou	Jr	3	0	Allison Corey	Fr	1	1
Nate Meredith	Grad	3	2	Lauren Eastes	Jr	2	0	Mackenzie Horton	Fr	1	1
Tam Nguyen	Grad	3	2	Bryan Ford	Jr	2	2	Michael Kalinowski	Fr	0	0
Tom Anderson	Sr	0	0	Connie Jiang	Jr	2	2	Mehul Kulkami	Fr	1	1
Elizabeth Brown	Sr	3	2	Tommy Tang	Jr	3	2	Parker Kurlander	Fr	0	0
Zack Gala	Sr	2	0	Gabe Gidley	So	2	1	Taylor Martell	Fr	0	0
Benjamin Nagle	Sr	4	2	Julie Lin	So	1	1	Olivia Mitchinson	Fr	0	0
Eldy Zuniga	Sr	3	3	Laura Zeiler	So	1	1	Eric O'Neill	Fr	0	0
								Madhurima Yerra	Fr	0	0

Hull Design & Structural Analysis

This year, the design process of the hull of *ALLEGRO* resembled the process for *LEGACY*. MCCT included new members in the process to ensure conservation of talent in future years. Focal points of considertaion 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 our final hull form.

During a meeting early in the year, members were asked to sketch cross sections of the hull. After collecting the cross section sketches, they were drawn using Rhinoceros 5.0 and analyzed to calculate their section moduli. This data was used and compared to previous years' concrete strengths to test feasbility of each cross section. This session was also used to introduce new members to the hull design programs and increase the number of cross sectional designs.

While designing *ALLEGRO*, several considerations were taken into account with respect to stability. Poor performance from last year's canoe, *LEGACY*, led to this becoming an increased focal point. From this, a wider beam of 30 inches was decided upon. Also, the cross section of the hull was changed back to a more traditional cross sectional shape to assist with stability by more evenly distributing the buoyancy and improving paddler comfort.

Additionally, design changes were made to improve turning and tracking. The keel near both the bow and stern was sloped up over a greater distance to reduce the surface area under the water in those regions. This can be seen in Figure 4. With less surface area below the water, the canoe will meet a smaller moment due to resistance when making the turns, and as a result will turn quicker. To assist with tracking, the widest portion of the canoe was moved aft of the midplane. This orientation serves as a yaw stabilizer when moving forward. Though this will greatly hinder our tracking abilities while tracking backwards, it was assumed that this was neglible since the canoe will rarely move in reverse.

To achieve these design changes in the most effective manner, a female mold was used. This type of mold allowed the desired shape of the outside of the hull to be achieved during pour day and maintained through sanding.

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

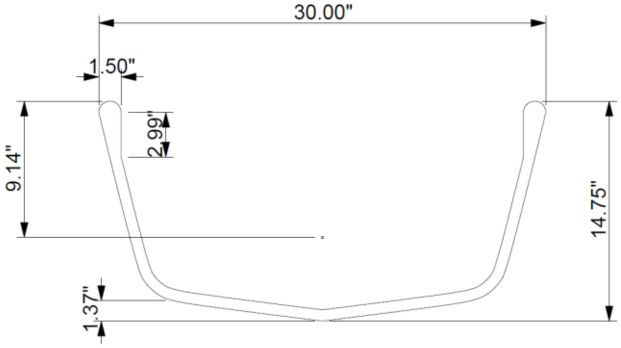


Figure 2: Midship cross section of *ALLEGRO*

The thickness of *ALLEGRO* was 0.75 inches and increased to 1.50 inches along the gunwhales. 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 gunwhale of the canoe when in tension.

To analyze the strength of *ALLEGRO*, seven different load cases were considered. Moments were calculated for the female races, the male races, the coed race, the empty canoe in water, the carrier, and stands. 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.

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

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 790 ft-lbs. Using this value with the stress formula, the maximum tensile force in the gunwale of *ALLEGRO* was calculated to be 94 psi. With a concrete tensile strength of 225 psi, the safety factor for this year's design is 2.38.

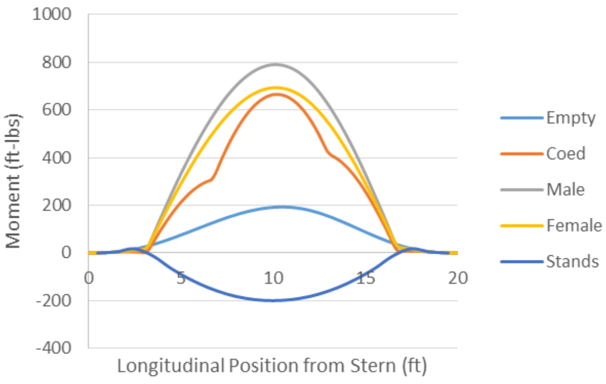


Figure 3: Loading cases for *ALLEGRO*

Additional analysis was completed to deterime resistance. Using the assumption that the hull would be smooth after sanding and sealing the canoe, and through the use of a female mold, 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

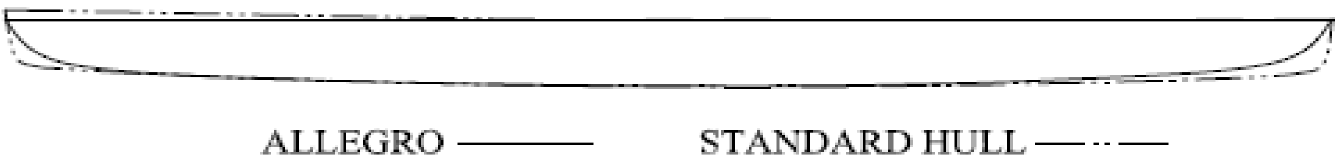


Figure 4: Comparison of keel lines of *ALLEGRO* and the standard hull

Development & Testing

Due to the strength and success of last year's mix design, MCCT decided to put its focus not in creating the strongest mix possible, but creating one with a reliable strength and lowest density seen by any active member. To achieve this goal, the team used multiple strategies in a systematic method to track the cause of any change in the mixes' properties. This method was done by focusing on the cementitious materials composition and the aggregate gradation, while maintaining the other components constant. The team selected this method to fully understand the effect of these two factors independently on the properties of the mix.

To ensure that the causes of any change to the mixes were completely clear, the mix leader adapted the system introduced last year, which used three baseline mixes to test different gradations. This year, the system was altered so that the mixes would evolve uniquely and independently. Each new integration changed either only the cementitious ratio or the aggregate gradation.

Figure 5: Measuring aggregates and cementitious materials during mixing

The cementitious materials used were Portland cement, Komponent, NewCem Slag Cement (GGBFS) and VCas-160. The team determined to keep the same cementitious materials to avoid introducing new variables into the mix design. Data collected from previous years allowed the team to understand the effects of these materials and their interactions with each other. Lack of extensive testing of other materials would create more unknowns, and thus would not allow the team to fine tune the mixes to the desired properties.

The manufacturing specifications for Komponent dictated that Komponent must comprise 15% of the total cementitious amount in all mixes. This requirement is to ensure the Komponent will still minimize the contraction of concrete while curing, and thus minimize cracking. The rest of the cementitious components were able to be heavily manipulated, creating a wide variety of combinations to be tested. In some base mixes, the overall cementitious to aggregate ratio was increased from 40 percent to 60 percent, which the team had maintained in previous years.

Figure 6: Testing increased cementitious to aggregate ratio

The second focus this year was the aggregate gradation for the mix. G850 was removed from the mix design because of its high density and minimal effect on the overall strength of the mix. The aggregates maintained were K20, three sizes of

Poraver (0.25 - 0.5, 0.5 - 1.0, and 1.0-2.0) and SG 900. The three aggregate base mixes evolved independently from each other, but were manipulated based on their corresponding cementitious counterparts.

In baseline one, the aggregate gradation was bottom heavy, meaning a higher proportion of smaller materials, to allow for better filling and increased strength. Consequently, the mixes' overall density increased, but was balanced by increasing proportions of lighter cementitious material such as VCas. Furthermore, to help fill more volume and lower the density, the remaining aggregate used was large hollow spheres to counterbalance the high density of the other materials.

The focus of baseline two was to maximize the strength of the mix. The team achieved this by increasing the proportions of Portland cement and raising the cementitious to aggregate ratio from last year's 40 percent to 60 percent. To maintain a light mixture, the aggregate gradation was mostly composed of large aggregates, with minimal small aggregates.

Baseline three was a hybrid of the two prior baseline mixes. This mix differed from the others by focusing primarily on changing the cementitious material composition and maintaining an even aggregate distribution.

The mixture iterations developed in different directions due to their independent baseline objectives. Including the three initial baseline mixes, a total of 18 mixes were made and tested. To ensure consistency amongst mixes, each mix was made, packed in cylinders, and tested for a 28-day strength according to ASTM C 109. During all testing, fibers were separated by hand to optimize even distribution throughout the mixes, as seen in Figure 7. Grace Fibers, made of polypropylene were maintained from last year due to their excellent performance in last year's final mix.

Figure 7: Separating fibers by hand

All mixes were packed into both 6 inch and 8 inch height cylinders, which were tested in compression and tension respectively.

Figure 8: Tensile testing of concrete cylinders

After compiling and receiving the expected stress on *ALLEGRO* from the hull design team, the final mix was chosen. The final mix is a variant of the baseline three mix, having a density of 58 lb/ft^3 which is 6 lb/ft^3 lower than the final mix used last year. Additionally, the tensile strength is 225 psi, a

25 psi reduction from last year's final mix. The compressional strength rose to 1110 psi, an increase of almost 70 psi from last year's final mix.

As for the other two mixes, baseline one seemed very promising and had a higher strength, but its density was slightly too high and needed finer tuning. Baseline two did not produce any real progress compared to the other two mixes and will be discontinued for next year's testing.

In recent years, the University of Michigan Concrete Canoe team has used a duct tape release agent because of its simplicity and low cost. However, this technique resulted in imprints in the hull from duct tape lines. Last year, the team began researching the use of liquid release agents, due to their ease of release and the smoother hull that would result.

Using the reports and Engineering Notebooks from various teams, along with internet searches, the team contacted several local companies inquiring about the use of liquid concrete release agents. Ultimately, the team narrowed down to two liquid release agents from Huron Technologies.

Upon receiving samples at the end of last year, we began testing the release agents. The team used four foam female molds from last year to test the release capabilities and resulting slump for the following cases: duct tape, Release Coating #7410, Release Coating #7572, and bare foam. After mixing a batch of concrete, the team applied this to the foam molds. Once the concrete had cured, the team attempted to separate the concrete from the mold for each case. The team found that concrete applied with the liquid Release Coating #7572 did not separate well and cracked before it could be fully removed. The concrete applied with duct tape and Release Coating #7410 were easily removed, but it was observed that slumping was more prevalent when the duct tape was used. After several trials, the team ultimately decided to switch to the Huron Technologies Release Coating #7410.

Figure 9: Testing release methods using female mold sections

As previously stated, the team's goal this year was to experiment and understand the different effects of certain compositions on cementitious and aggregate configurations. To properly achieve this, all the other components of the mixes, such as fibers and latex, were kept consistent between all mixes. Additionally, Glenium 7500 and AE90, a superplasticizer and air entrainer, respectively, remained in the mix, similar to last year. The Spiderlath Fiberglass Mesh and Grace Fibers, introduced last year, were also maintained due to their excellent performance.

Construction

This year, the mold selection process began with researching a manufactured mold. This strategy would create a smoother and more precise mold, while also cutting down on mold manufacturing person-hours, but was deemed too expensive for the team's budget. It was decided to create the mold out of three inch foam, the same as last year. This year, though, a female mold was decided to better suit the team's needs. While more material was needed for this female mold compared to a male mold, the female mold created an outer hull that was smoother, and thus required less sanding while maintaining the designed hull shape.

To create the mold, a 3-D model of the canoe was created in Rhinoceros 5.0. The model was then inserted in a block in Rhinoceros to create the female mold. Four 2"x4"x8' alignments were cut into the mold longitudinally. The female mold was then partitioned into 85 cross sections of three-inch thickness. The cross sections were fit into fifteen 4'x8' sections to be read by a CNC router. The CNC router was used to cut the foam sections from the sheets, as shown below. 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 10: CNC router cutting sections from foam sheets

To create the form of the gunwale, sections were made in Rhino and cut into reinforced cardboard. This allowed the gunwales to be formed in the mold without having to place a full mold on top of the female mold.

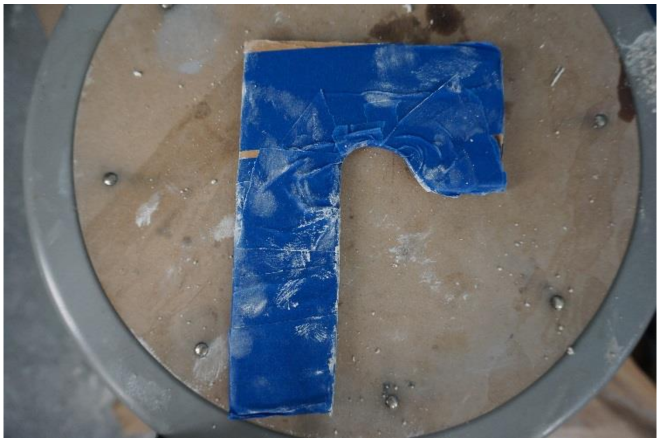


Figure 11: Gunwale mold

To ensure proper alignment and directionality of the cross sections, 2"x4"x8' wooden beams were placed on a leveled table. The mold was loaded onto the alignment beams and assembled using wood glue. The mold was sanded and spackled to mitigate any imperfections created by the CNC router.

Unlike previous years, a liquid release agent was used instead of duct tape. This choice was made to eliminate lines in the canoe created by duct tape and was found to have much less concrete slumping, a large concern with the use of a female mold. As the concrete was placed, the mold was coated with the release agent using paint brushes.

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 4 teams: mixing, fiber separation, concrete placement, and quality control. 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 in the mold. To maintain the constant mixing and placing process, the fiber separation team continuously separated fibers.

The first layer of concrete was 3/8”. 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 was 3/8” for most of the hull, but increased with the gradient near the gunwale. The gunwale was 1.5” at its thickest point and protruded above the top of the female mold. The gunwale required constant attention by team members to ensure it did not slump in or hang over the edge of the mold, thus maintaining the correct shape. The top layer of concrete was compacted and smoothed using trowels.

The quality control team used the instruments seen below to ensure consistency of the thickness of the canoe as it was being placed.

Figure 12: Quality control devices

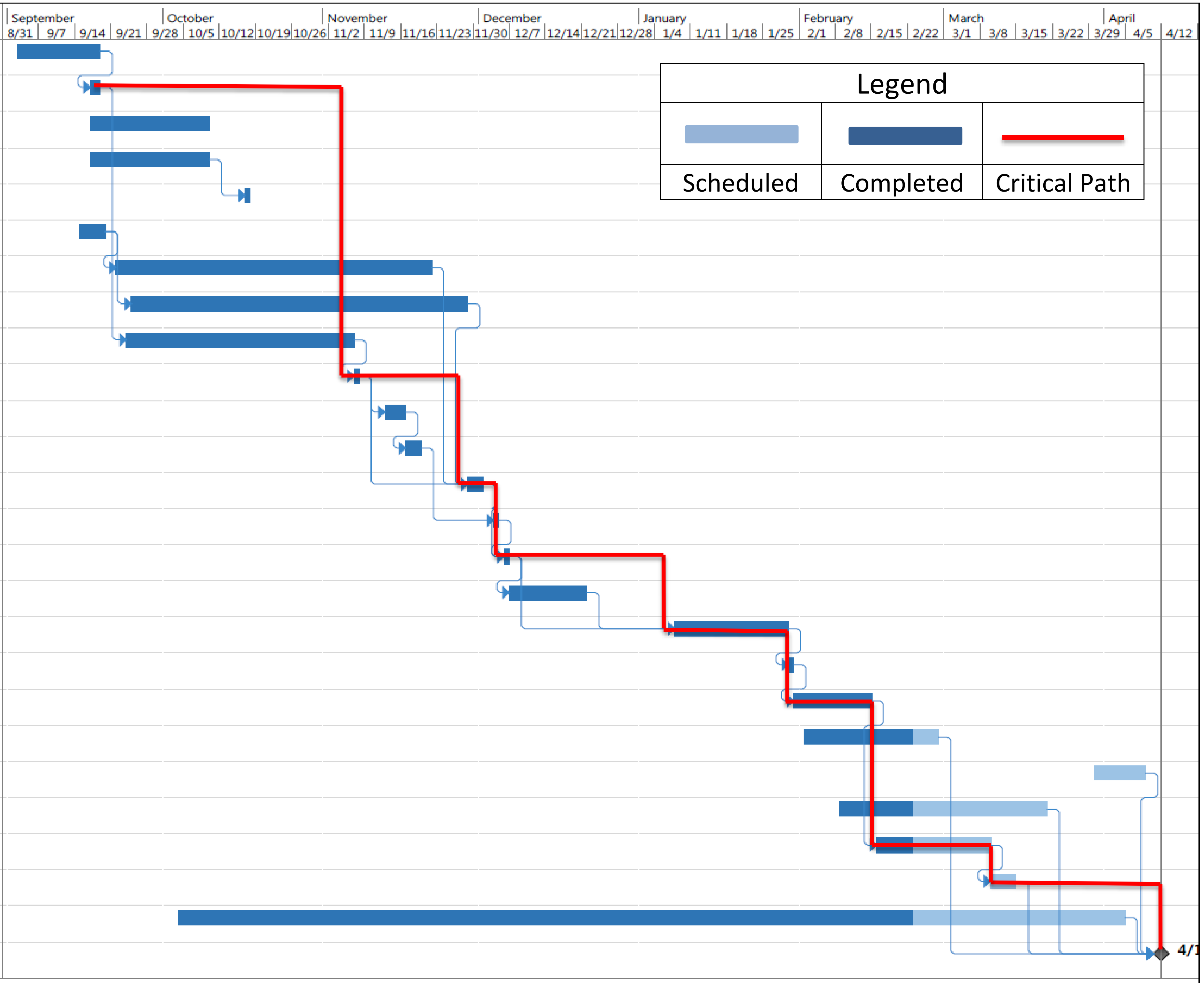
Three sizes of quality control devices were used in *ALLEGRO’s* construction. The devices were made from a nail pushed through a cork with the sharp end of the nail protruding either 3/8”, 3/4”, or 1.5”. The 3/8” device was used for the first layer, the 3/4” was used for the second, and the 1.5” was used for the gunwale at its thickest point. In addition to the quality control devices, a piece of re-enforced cardboard molds were used with the desired radius and gradient of the gunwale to ensure the gunwale was uniform throughout the canoe.

After pour day, the canoe was wet cured in a temperature controlled room for fourteen days over the winter break. Once cured, the interior of the canoe was sanded smooth and slurry coats of concrete were applied to fill in any imperfections in the concrete. Hand sanding was primarily used, but power sanding was used sparingly in areas of concrete buildup due to defects in the mold. *ALLEGRO* was de-molded by flipping it into a male mold that was created with the CNC router. The outside of the canoe was sanded smooth to prepare it for staining in accordance with our jazz theme and sealed to protect the design. The canoe will be swamp tested to determine whether or not additional flotation will be necessary.

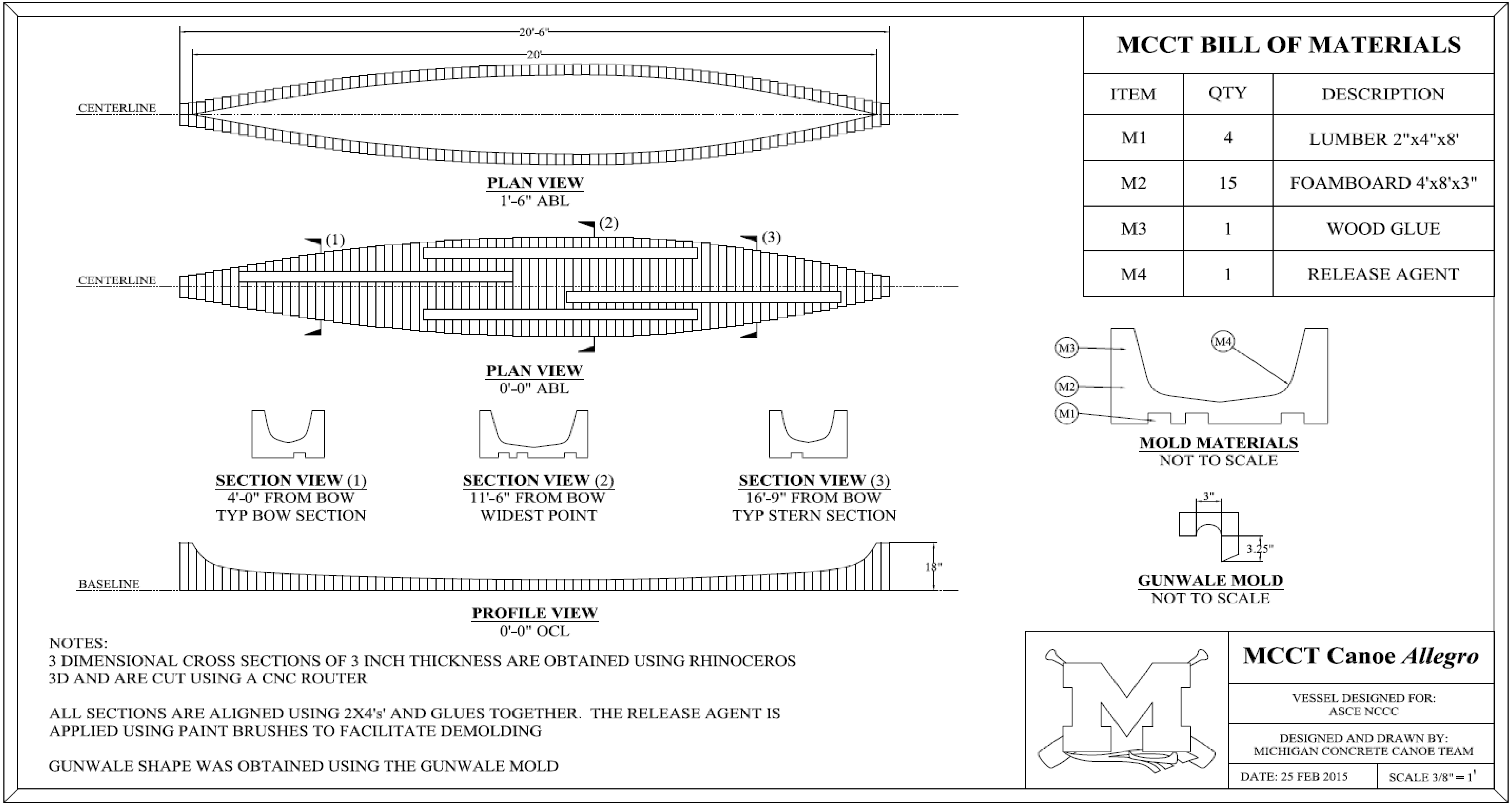
Sustainability was considered a focus for this year’s project, which was achieved through selection of cementitious materials and procurement of materials. Leftover materials from previous years were utilized to lower costs of the overall project. Additionally, MCCT worked to purchase materials such 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	Finish
1	New Member Recruitment	16 days	Wed 9/3/14	Thu 9/18/14
2	Mass Meeting	2 days	Wed 9/17/14	Thu 9/18/14
3	Determine Theme	23 days	Wed 9/17/14	Thu 10/9/14
4	Draft Sponsorship Letters	23 days	Wed 9/17/14	Thu 10/9/14
5	Mail Sponsorship Letters	1 day	Fri 10/17/14	Fri 10/17/14
6	Materials Research	5 days	Mon 9/15/14	Fri 9/19/14
7	Test Mixing	61 days	Mon 9/22/14	Fri 11/21/14
8	Cylinder Testing	65 days	Thu 9/25/14	Fri 11/28/14
9	Hull Modeling	44 days	Wed 9/24/14	Thu 11/6/14
10	Final Hull Selection	1 day	Fri 11/7/14	Fri 11/7/14
11	Arrage Cut Paths	4 days	Thu 11/13/14	Sun 11/16/14
12	Mold Cutting	3 days	Mon 11/17/14	Wed 11/19/14
13	Final Mix Selection	1 day	Sat 11/29/14	Mon 12/1/14
14	Mold Assembly and Preparation	1 day	Thu 12/4/14	Thu 12/4/14
15	Place Canoe	1 day	Sat 12/6/14	Sat 12/6/14
16	Canoe Curing	15 days	Sun 12/7/14	Sun 12/21/14
17	Interior Sanding	22 days	Thu 1/8/15	Thu 1/29/15
18	De-mold Canoe	1 day	Fri 1/30/15	Fri 1/30/15
19	Exterior Sanding	15 days	Sat 1/31/15	Sat 2/14/15
20	Technical Paper Writing	26 days	Mon 2/2/15	Fri 2/27/15
21	Technical Presentation Practice	10 days	Mon 3/30/15	Wed 4/8/15
22	Design and Construct Display	40 days	Mon 2/9/15	Fri 3/20/15
23	Staining Canoe	22 days	Mon 2/16/15	Mon 3/9/15
24	Sealing Canoe	5 days	Tue 3/10/15	Sat 3/14/15
25	Paddling Practice	183 days	Sat 10/4/14	Sat 4/4/15
26	Competition	3 days	Thu 4/9/15	Sat 4/11/15



Design Drawing



MCCT BILL OF MATERIALS

ITEM	QTY	DESCRIPTION
M1	4	LUMBER 2"x4"x8'
M2	15	FOAMBOARD 4'x8'x3"
M3	1	WOOD GLUE
M4	1	RELEASE AGENT

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

GUNWALE SHAPE WAS OBTAINED USING THE GUNWALE MOLD

MCCT Canoe *Allegro*

VESSEL DESIGNED FOR:
ASCE NCCC

DESIGNED AND DRAWN BY:
MICHIGAN CONCRETE CANOE TEAM

DATE: 25 FEB 2015 | SCALE 3/8" = 1'

Appendix A: References

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Appendix B: Mixture Proportions

Mixture ID: Structural Mix					Design Proportions (Non SSD)[1]		Actual Batched Proportions[2]		Yielded Proportions[3]	
YD	Design Batch Size (ft3):		0.39							
Cementitious Materials				SG[4]	Amount (lb/yd3)	Volume (ft3)	Amount (lb)	Volume (ft3)	Amount (lb/yd3)	Volume (ft3)
CM1	Portland Cement Type I			3.15	280.00	1.425	4.04	0.021	285.02	1.45
CM2	GGBFS			2.90	105.00	0.580	1.52	0.008	106.88	0.59
CM3	Komponent			3.10	105.00	0.543	1.52	0.008	106.88	0.55
CM4	VCAS			2.60	210.00	1.29	3.03	0.02	213.77	1.32
Total Cementitious Materials:					700.00	3.84	10.11	0.06	712.56	3.91
Fibers										
F1	Grace Fibers			1.30	3.00	0.037	0.04	0.001	3.05	0.04
Total Fibers:					3.00	0.037	0.04	0.001	3.054	0.038
Aggregates										
A1	Poraver 1.0 - 2.0	Abs:	19[5]	0.40	105.00	4.207	1.52	0.061	106.88	4.28
A2	Poraver 0.5 - 1.0	Abs:	18	0.50	85.60	2.744	1.24	0.040	87.14	2.79
A3	Poraver 0.25 - 0.5	Abs:	21	0.70	81.90	1.875	1.18	0.027	83.37	1.91
A4	SG 900	Abs:	1	0.72	94.50	2.103	1.37	0.030	96.20	2.14
A5	K20	Abs:	1	0.20	53.00	4.247	0.77	0.061	53.95	4.32
Total Aggregates:					420.00	15.175	6.07	0.219	427.54	15.45
Water										
W1	Water for CM Hydration (W1a + W1b)			1.00	349.30	5.598	5.05	0.081	355.57	5.70
	W1a. Water from Admixtures				56.07		0.81		57.07	
	W1b. Additional Water				293.23[6]		4.24		298.49	
W2	Water for Aggregates, SSD			1.00	36.30[7]		0.52		36.95	
Total Water (W1 + W2):					385.60	5.60	5.57	0.081	392.52	5.70
Solids Content of Latex Admixtures and Dyes										
S1	Dow Liquid Latex Modifier			1.05	51.01	0.78[8]	0.74	0.011	51.93	0.79
S3	Dow Liquid Latex Modifier									
Total Solids of Admixtures:					51.01	0.78	0.74	0.011	51.928	0.793
Admixtures (including Pigments in Liquid Form)				% Solids	Dosage (fl oz/cwt)	Water in Admixture (lb/yd3)[9]	Amount (fl oz)	Water in Admixture (lb)	Dosage (fl oz/cwt)	Water in Admixture (lb/yd3)
Ad1	Water Reducer	*8.9[10*	*lb/gal*	5	8.00	3.70	0.81	0.053	8.14	3.77
Ad2	Air Entrainer	*8.7*	*lb/gal*	5	3.00	1.36	0.30	0.020	3.05	1.38
Ad3	Liquid Latex Modifier	*8.8*	*lb/gal*	47	200	51.01	20.22	0.737	203.59	51.93
Water from Admixtures (W1a):						56.07		0.81		57.07
Cement-Cementitious Materials Ratio					0.400		0.400		0.400	
Water-Cementitious Materials Ratio					0.499[11]		0.551		0.551	
Slump, Slump Flow, in.					4±1		3.000		4±1	
M	Mass of Concrete. lbs				1559.62		22.53		1587.60	
V	Absolute Volume of Concrete, ft3				25.43		0.37		25.89	
T	Theorectical Density, lb/ft3 = (M / V)				61.33		61.33		61.33	
D	Design Density, lb/ft3 = (M / 27)				57.76					
D	Measured Density, lb/ft3						58.80		58.00	
A	Air Content, % = [(T - D) / T x 100%]				5.81		4.12		5.43	
Y	Yield, ft3 =				27		0.383		27	
Ry	Relative Yield = (Y / YD)						0.982			

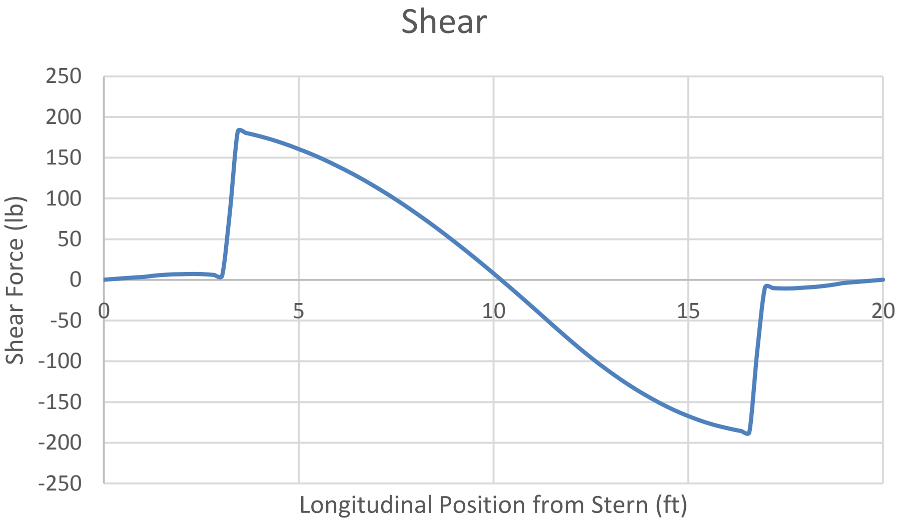
Appendix C: Bill of Materials

Material	Quantity (lbs)	Unit Cost	Total Price
Federal White Portland Cement Type I	44.88	0.27	$12.12
NewCem® GGBFS	16.83	0.05	$0.84
Komponent	16.83	0.24	$4.04
VCAS	33.66	0.76	$25.58
PP Fiber	0.48	7	$3.36
K20	8.49	5.4	$45.85
SG-900	15.15	6.25	$94.69
Poraver® 0.5-1 mm	13.72	0.7	$9.60
Poraver® 0.25-0.5	13.13	0.7	$9.19
Poraver® 1.0 - 2.0	16.83	0.7	$11.78
Sikalatex	8.18	1.29	$10.55
ADVA Cast 555	0.64	12.38	$7.92
Darex II	0.23	9.37	$2.16
Fiberglass Mesh (sq ft)	45	0.5	$22.5
CR-WRC Stain (oz)	40	1.88	$75.20
ChemMasters Crystal Clear Sealer (gal)	2	14.00	$28.00
Huron Technologies Release Coating #7410 (gal)	0.33	30.00	$10.00
Paint for Lettering (oz)	4	2.5	$10.00
Foam Mold, Complete	1 mold	1,650	$1,650
Sand Paper	1 pack	28	$28.00
Total Production Cost			**$ 2,061.38**

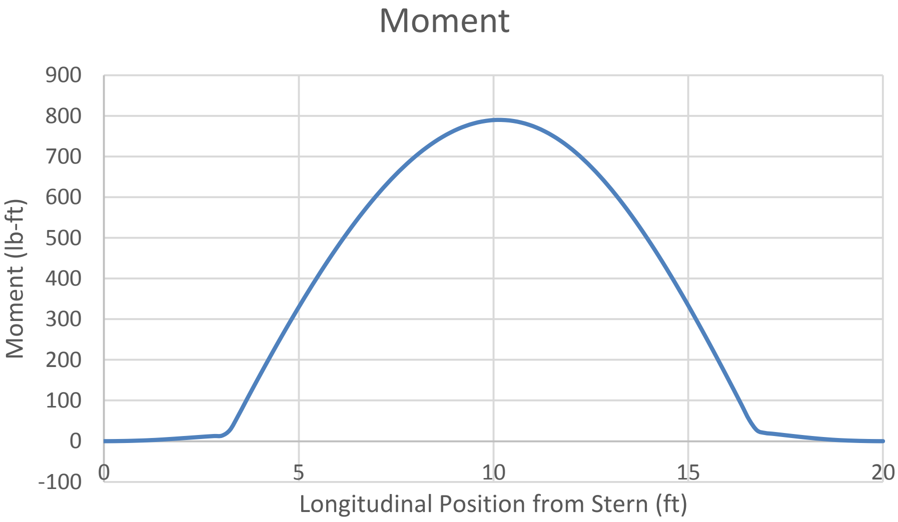
Appendix D: Example Structural Calculation

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

The following shear force graph was taken 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 790.4 lb-ft.



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.

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

$$M_{max} = max\ bending\ moment = 9484.8\ \ lb - in$$

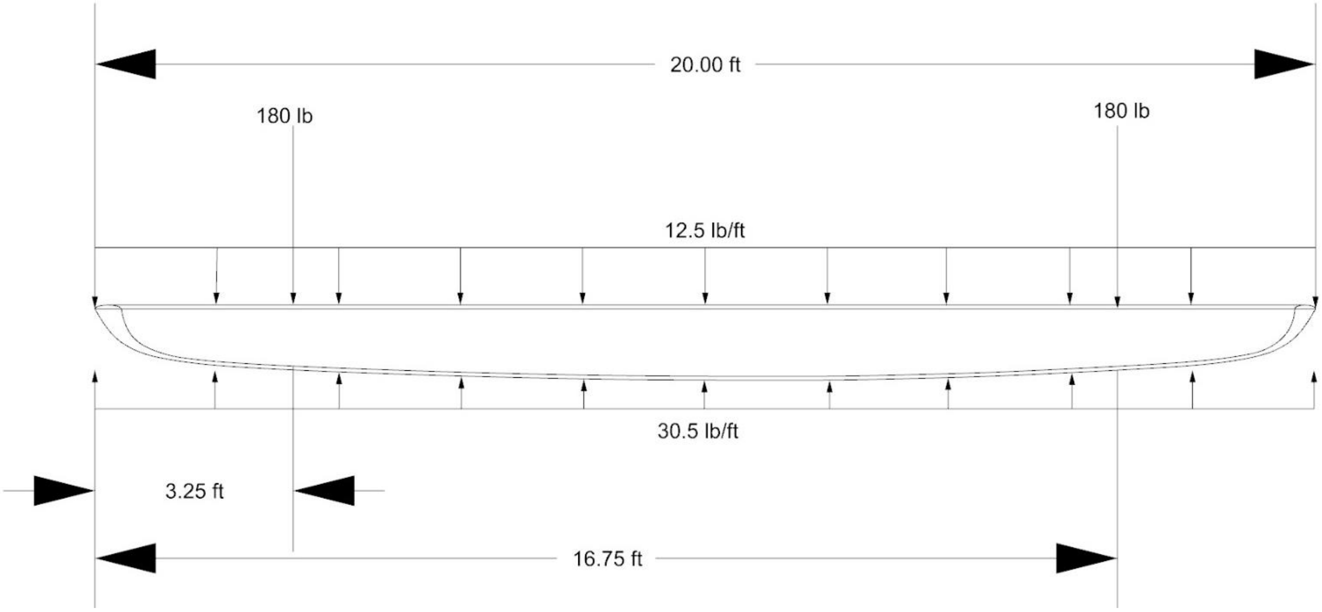
$$y = moment\ arm = 8.87\ in$$

$$I = area\ moment\ of\ inertia\ about\ neutral\ axis = 891.7\ in^4$$

$$\sigma = \frac{9484.8\ lb - in * 8.87\ in}{891.7\ in^4}$$

$$\sigma = \frac{84130.2\ lb - in^2}{891.7\ in^4}$$

$$\sigma = 94.3\ psi$$



Male sprint loading condition