LEGACY

University of Michigan
2014 Concrete canoe design paper

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Executive Summary

Founded in 1817, the University of Michigan of Ann Arbor has long been established as one of the nation's premier research institutions. The opening of the College of Engineering in 1854 served to only further the college's commitment to pursuing the latest, cutting-edge technology. Tackling the final frontier of space, the Apollo 15 mission, with an all-University of Michigan manned crew and NASA's fourth lunar landing, solidified Michigan as pioneers. Michigan Engineering faculty and students have continued this legacy of research and innovation, through student design teams such as the Michigan Concrete Canoe Team (MCCT). Facilities available through the Wilson Student Project Team Center continue to give students resources and opportunities to bring inventive ideas into reality. The 2014 canoe, *LEGACY*, is both a tribute to the Apollo 15 mission, and a commitment to future endeavors.

The Apollo 15 mission was the first mission to use a lunar rover, allowing the crew to explore more of the moon than in previous missions. Similarly, MCCT students explored previously unknown territory at the 2013 North Central Regional competition hosted by Michigan Technological University, where they finished with an overall placement of sixth place with the 2013 canoe *DREKAR*. Previously, the 2012 canoe *CRONUS* placed fourth overall and the 2011 canoe *IT'S A TRAP* placed fifth overall.

MCCT's newest endeavor, *LEGACY*, is manned by a mixed crew of experienced veterans and new recruits. The new members have brought many skills and allowed the team to make significant changes to the hull design of this year's canoe to reduce drag and increase paddler maneuverability. This year's hull design introduced a keel that would help paddlers have better maneuvering in the water during racing. The team switched the mesh to one that was more pliable, and thus able to conform to the new shape of the hull. In addition, an emphasis was placed on increased formal instruction and practice sessions for paddlers to build endurance and group cohesion. By scheduling an earlier pour day, the team's project schedule allowed more time to make fine adjustments to the canoe and increased detail in sanding.

Venturing into the unknown with the skills necessary to chart a new course of discovery, the Michigan Concrete Canoe Team presents the 2014 canoe *LEGACY*.

LEGACY	
Weight	220 pounds
Length	19 feet, 8 inches
Width	28.5 inches
Depth	14 inches
Average Hull Thickness	1 inch
Concrete Colors	Gray
Concrete Unit Weight	55.15 lb/ft^3 (wet) / 55.13 lb/ft^3 (dry)
Compressive Strength	1030 psi
Split Tensile Strength	250 psi
Reinforcement	Fiberglass mesh

Project Management

The goal for MCCT this year was for team members develop experience in all areas of the design process, thus supporting the longevity of the team. As a result of this objective, quality assurance was a major focus because many members were involved in each area, and team leads were charged with verifying all steps to ensure guidelines were met for both safety and feasibility.

This year's project began on August 30, 2013 with the first of the MCCT recruiting events. Once the NCCC rules were released, hull design and mix design began. The 2013-2014 project schedule closely follows the outline set forth by the 2013 canoe, *DREKAR*. Milestone activities were identified as the beginning of a new project phase that supports the critical path events. The following milestone activities were identified: recruit new members, reach out for sponsorship, mix & test concrete samples batches, cut & assemble mold, place canoe, sand & de-mold, stain and seal, and create display & stands.

The critical path events that supported the completion of *LEGACY* are as follows: mass meeting, finalize mix and hull design, construct mold, place canoe, de-mold, complete aesthetic design, and attend competition.

Risk of deviating from the critical path schedule was assessed, and buffers between events were applied appropriately to support the "place canoe" event. The canoe was placed on December 7, 2013, on schedule to support the March completion date.

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.

This year's project was divided into four main categories. An emphasis was placed on resource acquisition because the team wanted new capital goods such as paddles and a canoe carrier. Total man hours for the project are divided as follows:

Table 1: Division of project man hours.

Task	Hours
Research and Development (concrete material, testing test cylinder preparation and documenting findings)	210
Hull Design (3-D modeling, preparation of CNC router sheets, analyzing structure components)	150
Construction (cutting foam sheets, mold assembly, pouring, testing, canoe carrier and stand assembly, finishing the canoe)	420
Resource Acquisition (recruiting new members, finding potential sponsors, purchasing materials and capital goods, scheduling facility time)	100

The budget for *LEGACY* was $8000, slightly higher than that of last year's canoe *DREKAR*. Funding came from donations from local companies for materials and sponsorship from university departments and engineering societies. Major expenses included construction material, concrete material and capital expenses. This year, additional resources were also applied for use on more paddling practice, recruiting, and display materials. The total cost of the project is $7500, but will increase as competition approaches.

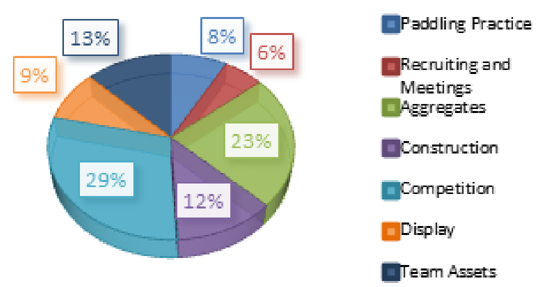
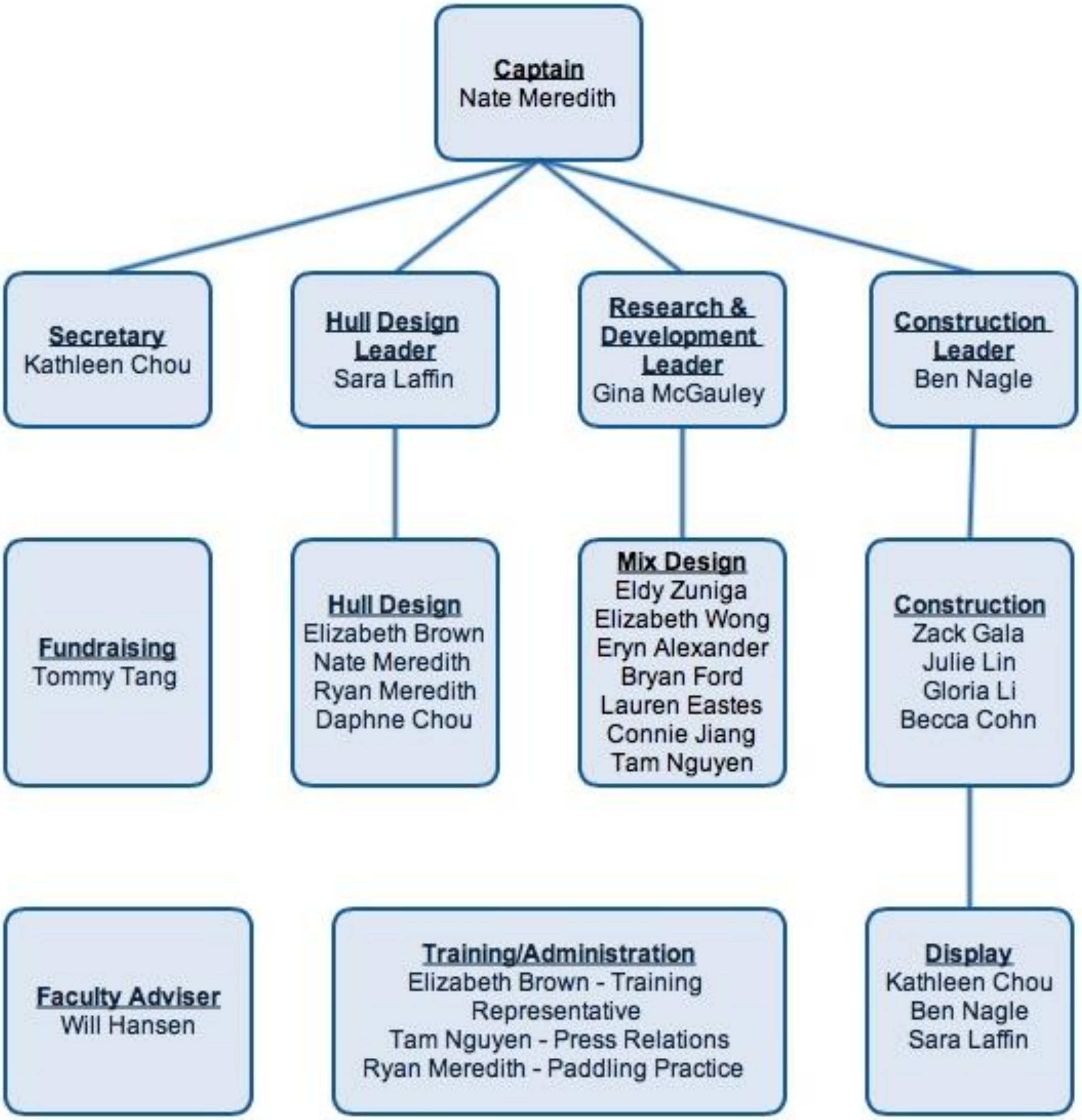


Figure 1: 2014 budget allocations.

Organization Chart



Hull Design & Structural Analysis

This year, the team began the design of *LEGACY* with a different approach from previous years in order to meet our design criteria. MCCT wanted to include new members in the design process while building an efficient hull that would track better through the water while making it easy for paddlers to propel the boat through the water.

The first step in design was to take the Standard Hull Form and use Maxsurf Stability Suite to parametrically transform the hull for different beam-to-length ratios. This would create a database of principal dimensions that would allow us to better understand the acting bending moment once a cross section was determined.

When picking the cross section, the entire team was involved. The team was looking for innovative designs, so a few meetings were dedicated to have members sketch out different cross sections they felt would be the best for speed, paddler comfort, and minimize acting stresses. From the collected results, the cross sections were analyzed in Rhinoceros 5.0 for the section modulus which would later be used with the regression of the principal dimensions. This was a great opportunity to teach new members the computer programs we rely on, as well as the driving equations considered during canoe design.

There were several important considerations when designing *LEGACY*. A narrower beam was desired to increase speed, tracking, and allow for easier paddler reach. Using the database created above, a beam of 28.5 inches was decided upon as it minimized bending moment under the max bending moment configuration of the male sprint race.

With a narrower beam, stability became more of an issue with the design. The outward curvature of walls of the canoe, flare, was added to help counteract the beam. Flare will increase stability when rolling because the righting arm increases faster compared to a standard canoe hull form. The final cross section design chosen for *LEGACY* is shown in Figure 2.

Figure 2: Midship cross section of *LEGACY*.

With these new design changes and a unique cross section, the strength of *LEGACY* was ensured by increasing the hull thickness from the previous year. The team decided on a minimum hull thickness of 0.75 inches along the keel to a maximum thickness of 1.2 inches along the gunwale. The purpose of this gradient thickness is to decrease the maximum bending arm and minimize the stress along the gunwale when the canoe is in tension. The driving factor was the unconventional hull shape, with extra curvature around the keel. Figure 4 portrays the design of the gradient thickness of the hull.

Seven different loading conditions were analyzed when considering the strength of *LEGACY*. Moments were calculated for the following conditions: male, female, and co-ed race conditions, an unloaded canoe in the water, the canoe in the transport carrier, the canoe on its race day stands, and the display day stands.

The tensile stress in the gunwales was calculated using the maximum distance from the neutral axis, *D*, the moment of inertia, *I*, and the global bending moment, *M*, as seen in Equation 1 below.

$$\sigma = \frac{M * D}{I} \quad \text{(Eqn. 1)}$$

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 around 756 ft-lbs. Using this value with the stress formula, the maximum tensile force in the gunwale of *LEGACY* will be about 96 psi. With a concrete tensile strength of 250 psi, the safety factor for this year's design is 2.6.

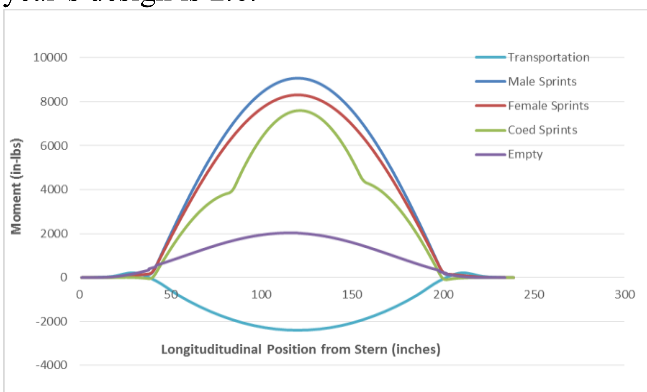


Figure 3: Loading cases for *LEGACY*.

The next analysis focused on resistance calculations. Assuming approximately smooth conditions after sanding and sealing the canoe, the frictional resistance coefficient, C_F, can be approximated using the skin friction line developed by the International Towing Tank Conference (ITTC 1978), shown in Equation 2.

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

Re_S, is the length Reynolds number dependent on the kinematic viscosity, ν and forward velocity V which can be found below.

$$Re_S = \frac{VL}{\nu}$$

With the C_F coefficient, the frictional resistance, R, can be found using the Equation 3 below.

$$R = C_F \frac{1}{2} \rho S V^2 \qquad \text{(Eqn. 3)}$$

Where ρ is density of water and S is the wetted surface area.

Using this approximation, the frictional resistance component was calculated to be 1.69 pound-force. A summary of these calculations is shown in Table 2 below.

Table 2: Resistance calculation summary.

V	$3.38 \frac{ft}{s}$	C_F	0.0035
L	$20\ ft$	ρ	$1.94 \frac{slug}{ft^3}$
ν	$1.61 * 10^{-5} \frac{ft}{s^2}$	S	$43.7\ ft^2$
Re_S	$4.199 * 10^6$	R	$1.69\ lb$

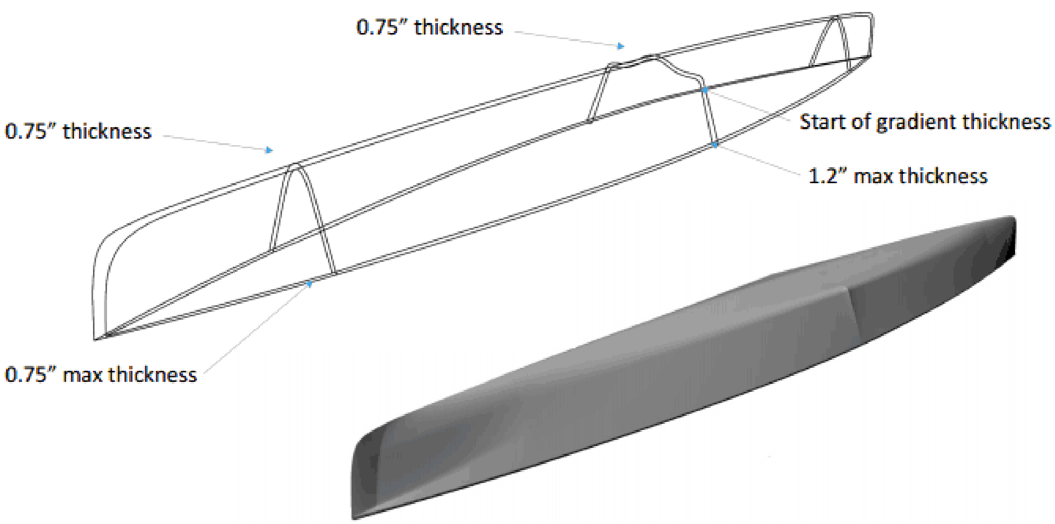


Figure 4: The final view of canoe with the thicknesses marked.

Development & Testing

MCCT's ultimate goals for this year were to develop a concrete mix with a density less than that of water, while maximizing the tensile strength of the mix. To accomplish this, MCCT tested three different proportions of aggregate to see their effects on these two metrics. Another major focus was to look for an optimal mix of our different cementitious materials including one that had not used before, VCAS, by varying the material quantities. Other elements altered included a new type of fiber that was tested in different quantities and experimented with a mix of two fiber lengths. The second approach lead to lower tensile strengths, so testing was discontinued.

Figure 5: Measuring aggregates and cementitious materials.

Aggregates used in all three baselines included K20, three sizes of Poraver (0.25 - 0.5, 0.5 - 1.0, and 1.0-2.0), SG 900, and G850. The major change from last year's mix was the removal of Haydite, an expanded shale that MCCT has used for several years. It was removed because its properties were not as uniform as the other materials. More uniformity allowed the team to better control what variabilities were tested. A second change was the switch from using K1 glass microspheres to K20. The K20 is a slightly denser aggregate, but this was compensated by the increase in strength it lent to the mix. The final concrete mix had good workability that allowed the team to easily smooth it over our mold during the canoe's construction.

MCCT's cementitious materials included Portland Cement Type I, Ground Granulated Blast Furnace Slag (GGBFS), and Komponent. GGBFS, a locally available steel production by-product as a sustainable, recycled, cementitious material, was used again. Rice Husk Ash was removed from this year's mix to create a lighter final color which allows for more flexibility when staining the canoe.

Figure 6: Formed cylinders during testing.

To create the baseline mix for this year, MCCT analyzed the mixes used by other teams over the past three years. The goal to drastically improve both the design's strength and density encouraged developing a mix vastly different from last year. The percentage of aggregate in the mix was set at 60% and the use of Portland cement as 40% of our cementitious material. Admixture dosages were kept constant from last year as the results obtained helped decrease the density and increase workability and strength. The admixtures used in *LEGACY* were Glenium 7500 and AE90, a superplasticizer and air entrainer, respectively.

The major change for the *LEGACY* mix was to use an innovative approach to select the aggregate distribution. The first mix had a flat gradation with equal percent of small and large aggregate (Baseline One). Modifications were made to test one mix which increased the percentage of small aggregate (Baseline Two) and a second one which increased the percentage of large aggregate (Baseline Three). A rough sketch of the three gradation curves can be seen in Figure 6. These curves are theoretical and not calculated; the size plotted on the graph is the estimated average size of each aggregate. This innovative approach for MCCT allowed the team to visualize the differences in the three baseline mixes. Baseline One, the flattest gradation, resulted in a significantly lower strength. The second baseline had a strength similar to last year's, but a low enough density to float. The third baseline had a compressive strength of about 1400 psi (approximate tensile strength of 280 psi) which exceeded our desired improvement, but was too dense to float.

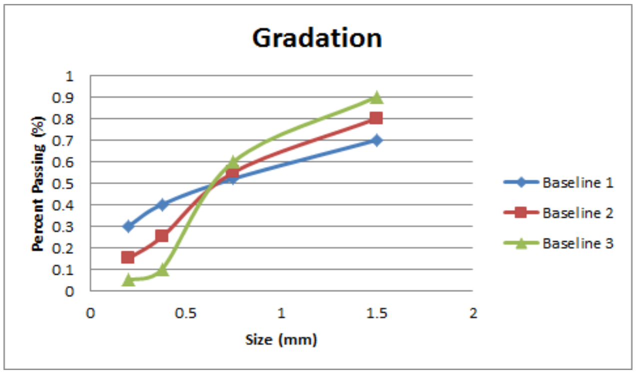


Figure 7: Qualitative gradation curves for Baseline mixes.

Fifteen subsequent test batches were mixed to try to create a mix that had the high strength of Baseline Three with the low density of Baseline Two. Cylinders were made from each test batch, and tested for 28-day strength according to ASTM C109. Modifications to each batch focused on the effect variations on the distribution of the cementitious material: Portland Cement Type I, GGBFS, and VCAS. The effect of using a single aggregate for the smallest size instead of two similar aggregates (G850 and K20) was tested. Using solely K20 significantly improved the strength of Baseline Three, but did not have the same desired effect on Baseline Two. Four additional batches were mixed to test different fibers as mentioned earlier. Polypropylene (PP) fibers were tested against the polyvinyl alcohol (PVA) fibers that have been used for the past several years.

After analyzing the results of all tests, MCCT decided that the original Baseline Two mix had the best combination of low density and high strength. The final mix modified Baseline Two by switching to PP fibers and increasing the amount of fibers in the mix. Cylinders made on Pour Day were tested for their 28-day compressive strength per ASTM standards, which was 1030 psi. While this is lower than the strength from last year, the tensile strength for this mix increased from last year to 250 psi. The decrease in compressive strength is acceptable for the structural integrity of the canoe, especially with the increase in tensile strength which was achieved. The final mix achieved our primary goal of a mix that was less dense than water. It also highly workable, allowing us to better control for thickness and uniformity on Pour Day.

Figure 8: Separating fibers for varying proportions in each text mix.

MCCT decided to use Spiderlath Fiberglass Mesh as reinforcement for the canoe this year for several reasons. To begin with, Spiderlath is lighter, is thinner, has a higher strength ratio, and is more flexible than mesh MCCT has used in the past. Additionally, the use of Spiderlath by several other teams in the conference has proven that it successfully prevents cracking with its high tensile strength. Finally, Spiderlath meets all competition requirements for open area and reinforcement standards. As MCCT designs more unique canoes, a mesh that can evolve with design complexity and remain sustainable was an important factor when picking a new mesh this year.

Construction

This year's construction method for *LEGACY* followed that of the previous year. The team used a male mold for the canoe, decreasing the amount of foam used and improving concrete adhesion during construction to mitigate the effects of slump on canoe thickness. To create the mold, a 3-D model of the canoe was created in Rhinoceros 5.0, which was then split into 85 cross sections of 3 inch thickness. Use of 3 inch foam rather than previous 2 inch foam for the mold helped reduce costs for MCCT due to purchasing fewer foam sheets and shorter CNC router cutting time. These sections were then laid into 4' x 8' sections, along with cutouts to fit three 2" x 4" alignment beams, and a CNC router was used to cut the individual pieces from a foam sheet. Flat bottom sections that had molds for the gunwale and alignment beams were added this year for easier removal of the mold once sanding was completed. 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 9: Cutting out male mold using CNC router.

One innovation for this year's construction involved aligning the mold using three offset spines instead of a single spine in previous years. Three 2" x 4" beams were used to align the vertical cutouts together and in the correct position on the bottom, horizontal piece of the mold. Three beams provided a greater alignment and ensured that there could be no twisting in the hull, an issue seen in previous years. The beams were offset to make correct mold placement easier (if a cross section was placed on the wrong side, it would not fit on top of the beams) and ensure better alignment in both the lateral and horizontal directions.

Figure 10: Aligning mold pieces on 2" x 4" beams.

The mold was placed on pre-leveled tables, aligned with the three alignment beams, and glued together using wood glue. The mold was lightly sanded, and the outer surface of the male mold was then covered in a layer of double wide duct tape, which makes de-molding much easier.

Unlike previous years, Pour Day for *LEGACY* was scheduled for the end of the fall semester. This was advantageous because this allowed *LEGACY* to cure over winter break, which allowed sanding to begin at the very beginning of the winter semester. This placed the team several weeks ahead of schedule in relation to previous years, allowing for a greater focus on detailed sanding and more time for other components such as the stands and display.

On Pour Day, 0.3 ft^3 batches of the chosen concrete were pre-measured and mixed. The concrete was then laid in a 3/8" first layer by hand, followed by a layer of fiberglass mesh for reinforcement. The mesh was laid in 3 foot sections with a 2 inch overlap, ensuring that there were not weaknesses due to gaps in mesh reinforcement. Latex was sprayed on the first layer after application to aid in the bonding of the two layers and the mesh. A final layer was then laid on, which was 3/8" on the bottom and ends, but thicker on the center walls due to the gradient gunwale. This layer was compacted by hand and smoothed using trowels.

Figure 11: Three sizes of quality control devices for hull thickness measurement.

Three sizes of quality control devices were used to ensure an even thickness in *LEGACY*'s hull. They consisted of a nail pushed through a cork, with the protruded end of the nail being either 3/8", 3/4", or 1". The 3/8" quality control device was used for the first layer of concrete, while the 3/4" device was used for the second layer. The 1" device was used to make sure our gradient thickness of the gunwale was correct. Four team members were assigned as "Quality Control Managers". These members constantly checked the hull thickness throughout the day, at all stages of construction. This job was more essential than in past years due to the difficulty in thickness consistency caused by *LEGACY*'s protruding keel.

After placement, the concrete was wet-cured in a temperature controlled environment for fourteen days. Once cured, the canoe exterior was thoroughly sanded, using both power sanders and hand sanding. After the outer hull had been well sanded, *LEGACY* was demolded and placed in a female mold, which was created using the same 3-D modeling and CNC cutting as the mold. The inner hull was then sanded. The canoe will be stained with a design in accordance with our space exploration theme, and then sealed to protect the aesthetic design. The canoe will be swamp tested to determine whether or not additional flotation will be necessary.

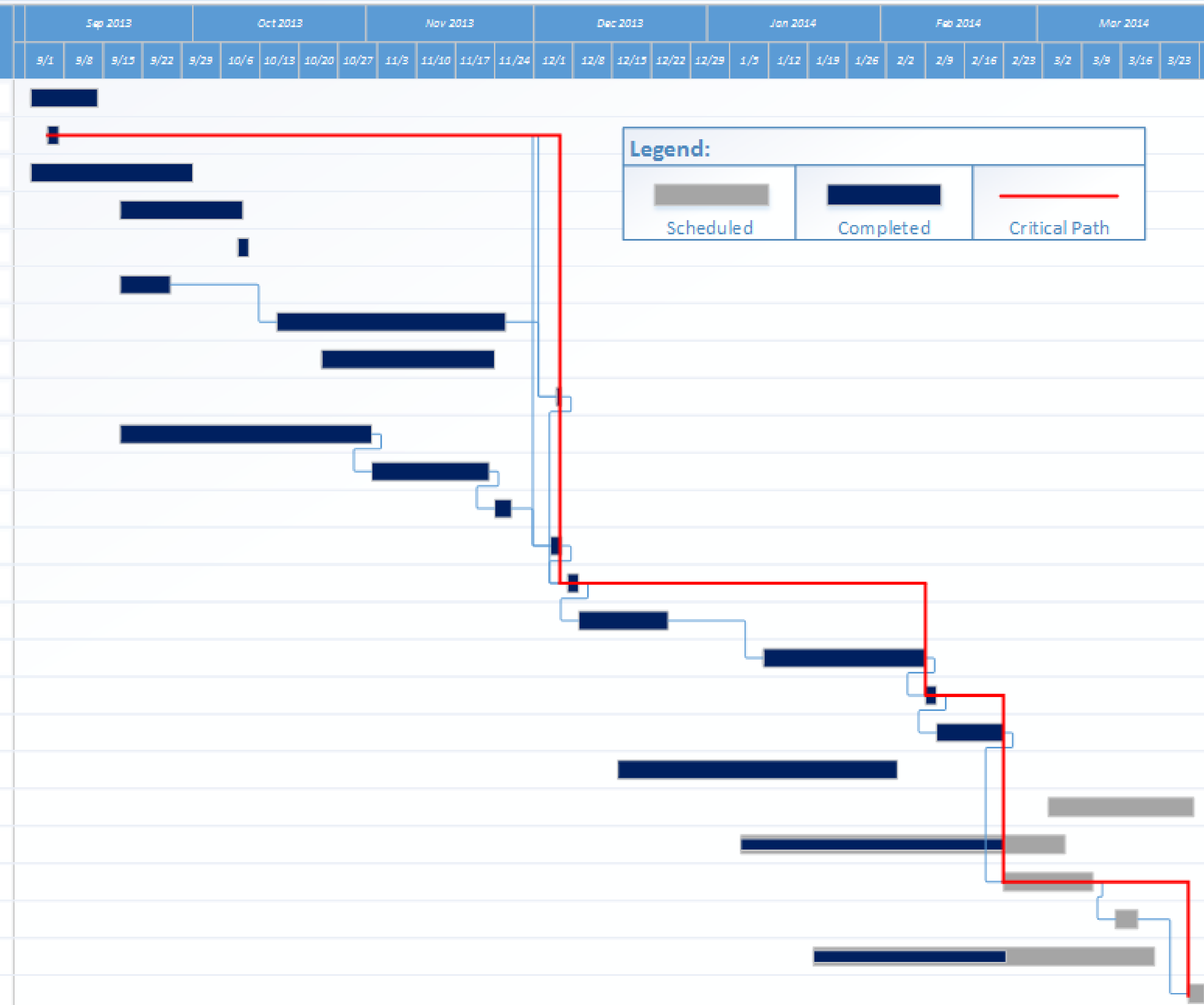
Figure 12: Placing concrete and checking hull thickness on Pour Day.

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.

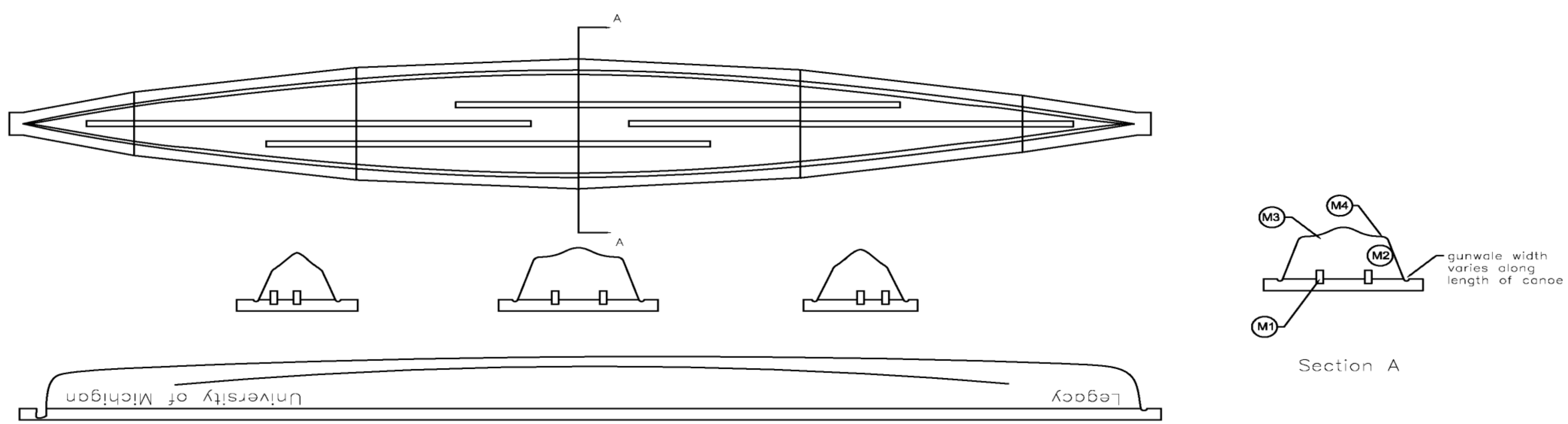
Figure 13: Hand sanding the interior of *LEGACY* after demolding.

Project Schedule

ID	Task Name	Start	Finish	Duration
1	New Member Recruitment	9/2/2013	9/13/2013	12d
2	Mass Meeting	9/5/2013	9/6/2013	2d
3	Determine Theme	9/2/2013	9/30/2013	29d
4	Draft Sponsorship Letters	9/18/2013	10/9/2013	22d
5	Mail Sponsorship Letters	10/9/2013	10/10/2013	2d
6	Materials Research	9/18/2013	9/26/2013	9d
7	Test Mixing	10/16/2013	11/25/2013	41d
8	Cylinder Testing	10/24/2013	11/23/2013	31d
9	Final Mix Selection	12/5/2013	12/5/2013	1d
10	Hull Modeling	9/18/2013	11/1/2013	45d
11	Arrage Cut Paths	11/2/2013	11/22/2013	21d
12	Mold Cutting	11/24/2013	11/26/2013	3d
13	Mold Assembly and Preparation	12/4/2013	12/5/2013	2d
14	Place Canoe	12/7/2013	12/8/2013	2d
15	Canoe Curing	12/9/2013	12/24/2013	16d
16	Exterior Sanding	1/11/2014	2/8/2014	29d
17	De-mold Canoe	2/9/2014	2/10/2014	2d
18	Interior Sanding	2/11/2014	2/22/2014	12d
19	Technical Paper Writing	12/16/2013	2/3/2014	50d
20	Technical Presentation Practice	3/3/2014	3/28/2014	26d
21	Design and Construct Display	1/7/2014	3/5/2014	58d
22	Staining Canoe	2/23/2014	3/10/2014	16d
23	Sealing Canoe	3/15/2014	3/18/2014	4d
24	Paddling Practice	1/20/2014	3/21/2014	61d
25	Competition	3/28/2014	3/30/2014	3d



Design Drawing



NOTES:
3 DIMENSIONAL CROSS SECTIONS OF 3 INCH THICKNESSES ARE OBTAINED ALONG THE LENGTH OF THE CANOE USING RHINOCEROS 5.0, TO BE CUT OUT USING A CNC ROUTER.

ONCE ALIGNED USING 2x4's AND GLUED TOGETHER, THE MOLD IS TO BE COATED IN DUCT TAPE TO FACILITATE DEMOLDING.

MCCT BILL OF MATERIALS

ITEM	QTY.	DESCRIPTION
M1	4	LUMBER 2"x4"x8'
M2	7	FOAMBOARD 4'x8'x3"
M3	1	WOOD GLUE
M4	1	DUCT TAPE COATING

Naval Architecture & Marine Engineering

MCCT Canoe - "Legacy"

VESSEL DESIGNED FOR:
ASCE NCCC

DESIGNED AND DRAWN BY:
Michigan Concrete Canoe Team

DATE: 2/28/2014 | SCALE: 3/8":1' | SHEET 1 OF 1

Appendix A: References

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Appendix B: Mixture Proportions

Mixture ID:					Design Proportions (Non SSD)		Actual Batched Proportions		Yielded Proportions	
Y_D	Design Batch Size (ft^3):		0.3							
Cementitious Materials				SG	Amount (lb/yd^3)	Volume (ft^3)	Amount (lb)	Volume (ft^3)	Amount (lb/yd^3)	Volume (ft^3)
CM1	Portland Cement Type I			3.15	280.00	1.425	3.11	0.016	263.09	1.338
CM2	NewCem GGBFS			2.99	315.00	1.688	3.50	0.019	295.98	1.586
CM3	Komponent			3.10	105.00	0.543	1.17	0.006	98.66	0.510
	Total Cementitious Materials:				700.00	3.66	7.78	0.041	657.73	3.435
Fibers										
F1	Grace Microfibers			1.30	8.00	0.099	0.09	0.001	7.52	0.093
	Total Fibers:				8.00	0.099	0.09	0.001	7.52	0.093
Aggregates										
A1	Poraver 1.0 - 2.0	Abs:	19	0.40	126.00	5.048	1.40	0.056	118.39	4.743
A2	Poraver 0.5 - 1.0	Abs:	18	0.50	75.60	2.423	0.84	0.027	71.04	2.277
A3	Poraver 0.25 - 0.5	Abs:	21	0.70	50.40	1.154	0.56	0.013	47.36	1.084
A4	SG 900	Abs:	1	0.72	42.00	0.935	0.47	0.010	39.46	0.878
A5	K20	Abs:	0.4	0.20	91.00	7.292	1.01	0.081	85.51	6.851
A6	G850	Abs:	30	2.10	35.00	0.267	0.39	0.003	32.89	0.251
	Total Aggregates:				420.00	17.119	4.67	0.190	394.64	16.085
Water										
W1	Water for CM Hydration (W1a + W1b)			1.00	350.00	5.609	3.89	0.062	328.87	5.270
	W1a. Water from Admixtures				58.39		0.65		54.86	
	W1b. Additional Water				291.61		3.24		274.01	
W2	Water for Aggregates, SSD			1.00	59.42		0.66		55.83	
	Total Water *(W1 + W2)*:				409.42	5.61	4.55	0.062	384.69	5.2703
Solids Content of Latex, Dyes and Admixtures in Powder Form										
S1	Latex (if used)			1.05	47.29	0.722	0.53	0.008	44.44	0.678
	Total Solids of Admixtures:				47.29	0.72	0.53	0.008	44.44	0.6782
Admixtures (including Pigments in Liquid Form)				% Solids	Dosage (fl oz/cwt)	Water in Admixture (lb/yd^3)	Amount (fl oz)	Water in Admixture (lb)	Dosage (fl oz/cwt)	Water in Admixture (lb/yd^3)
Ad1	Water Reducer	*8.9*	*lb/gal*	5.00	8.00	3.70	0.62	0.288	7.52	3.476
Ad2	Air Entrainer	*8.7*	*lb/gal*	5.00	3.00	1.36	0.23	0.105	2.82	1.274
Ad3	Liquid Latex	*9.2*	*lb/gal*	47.00	200.00	53.33	15.56	4.148	187.92	50.111
	Water from Admixtures *(W1a)*:					58.39		4.541		54.861
Cement-Cementitious Materials Ratio					0.400		0.400		0.400	
Water-Cementitious Materials Ratio					0.500		0.50		0.50	
Slump, Slump Flow, *in*.					4 +/- 1		3		3	
M	Mass of Concrete. *lbs*				1584.71		17.61		1489.02	
V	Absolute Volume of Concrete, *ft^3*				27.204		0.30		25.56	
T	Theorectical Density, *lb/ft^3*		*= (M / V)*		58.25		58.25		58.25	
D	Design Density, *lb/ft^3*		*= (M / 27)*		58.69					
D	Measured Density, *lb/ft^3*						55.149		55.149	
A	Air Content, %		*= [(T - D) / T x 100%]*		-0.75		5.33		5.33	
Y	Yield, *ft^3*		*= (M / D)*		**27.000**		0.319		27.000	
Ry	Relative Yield		*= (Y / Y$_D$)*				1.064			

Appendix C: Bill of Materials

Material	Quantity (lbs)	Unit Cost	Total Price
Federal White Portland Cement Type I	40.43	0.27	$10.92
NewCem® GGBFS	45.5	0.05	$2.28
Komponent	15.21	0.24	$3.65
PP Fiber	1.17	7	$8.19
K20	13.52	5.4	$73.01
SG-900	6.11	6.25	$38.19
G850	4.68	0.55	$2.57
Poraver® 0.5-1 mm	10.92	0.7	$7.64
Poraver® 0.25-0.5	7.28	0.7	$5.10
Poraver® 1.0 - 2.0	18.2	0.7	$12.74
Sikalatex	14.5	1.29	$18.71
ADVA Cast 555	0.56	12.38	$6.93
Darex II	0.2	9.37	$1.87
Fiberglass Mesh (sq ft)	42	0.5	$21.00
CR-WRC Stain (oz)	40	1.88	$75.00
Sealer (gal)	2	24.25	$48.50
Paint for Lettering (oz)	4	2.5	$10.00
Foam Mold, Complete	1 mold	813	$813.00
Sand Paper	1 pack	28	$28.00
Total Production Cost			**$1,187.29**