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EXECUTIVE SUMMARY

While Michigan Technological University (Michigan Tech) most notably provokes images of its long, harsh winters, the breathtaking summers in the Upper Peninsula of Michigan are not to be overlooked. With 1,700 miles of shoreline along three of the Great Lakes, it is no wonder that sailing is one of the most popular summer activities. Of course, no sailboat is complete without a genoa; a large, triangular sail deployed to gain speed and overtake the opposition. In their journey to sail past the competition, Michigan Tech's Concrete Canoe Team will rely on their own **GENOA** to succeed.

Founded as the Michigan College of Mines in 1885, Michigan Tech has become a leader in engineering technology. The Civil Engineering department was founded in 1930, with the school's American Society of Civil Engineering chapter following in 1931. The Michigan Tech Concrete Canoe Team proudly consists of students from nine different disciplines. This gives the team a diverse range of talent contributing to every facet of the competition.

Michigan Tech has been competing in the North Central Conference since 1978. The 2012 season marks the 13^{th} time the team has represented the conference at the National Concrete Canoe Competition (NCCC). A team-best finish of third place was achieved in 2005 with **The MacInnes**. Michigan Tech continued its strong showing, taking fifth place with **Keweenaw Miner** in 2006. The team advanced to the NCCC for two more consecutive years; ***Gitchee Gumee*** took tenth in 2007 and **Gambler** received eighth place in 2008. Although failing to advance to the national competition in 2009, the team returned with a vengeance and took fourth place with **YOOPER** in 2010. In 2011, Michigan Tech overcame a cracked canoe and defied the odds to achieve an impressive sixth-place finish with **FRONTIER**.

Michigan Tech's Concrete Canoe Team has traditionally been a leader in research and testing, and this year proved to be no different. The team refused to accept failure as an option, and made significant innovations within all aspects of the project. A more efficient and accurate method of analysis was used this year. From the unique shape of **GENOA** to the construction of gunwale caps, new key features are seen on this year's canoe. New materials were procured for testing, which allowed the team to expand its knowledge base. In an effort to conserve resources, a filtration system was designed and installed within the team's facility to reuse water. The 2012 NCCC rules allowed for increased creativity and flexibility with aesthetics, something Michigan Tech truly took advantage of. Throughout the 2012 season, the team gained a great wealth of new information and was prepared to use this newfound wisdom to make this season the best in Michigan Tech's history.

Table 1: Canoe specifications.

2012 Canoe Properties			
Weight	134 lbs	**Unit Weight**	55.4 pcf
Length	18.5 feet	**Compressive Strength**	2112 psi
Width	31 inches	**Tensile Strength**	323 psi
Depth	12.2 inches	**Continuous Reinforcement**	Kevlar Fabric 4009-1
Nominal Thickness	0.375 inches	**Fiber Reinforcement**	Nycon Kuralon RF4000 and RECS15 Polyvinyl Alcohol Fibers
Main Color	White	**Rib Reinforcement**	Loose-Strand Carbon Fiber

HULL DESIGN

Michigan Tech, excited to have hull design as part of the competition again, began its research and planning as soon as the rules were released. The team started off the season with six design objectives; the canoe should:

- weigh less than 120 pounds
- require minimal straight-line correction
- round a buoy in less than two draw strokes
- have adequate primary stability
- provide paddlers with easy access to water
- increase paddler comfort

After weeks of evaluation, a hull design was chosen for GENOA. The result is a modified version of the team's 2005 canoe, **The MacInnes**. Alterations to the design sought to decrease turbulence along the bottom of the canoe and improve ease of paddling. A low-cost prototype was built out of Luann wood and was dubbed **Laker**. This promises to be an effective method of creating prototypes in the future.

GENOA's key feature is a subtle reverse chine in its bow, which allows water to be guided under the canoe, creating lift. This enables the canoe to ride up onto its bow wave, thus distinguishing the design as a semi-displacement hull. Michigan Tech's previous displacement hull canoes had features that exponentially increased wave-making drag as velocity increased, limiting the canoe's attainable speed. With a semi-displacement hull, the wave-making resistance experienced by GENOA at high velocities is capped.

During the 2008 competition, the team realized a canoe's straight-lining ability largely depends on the size of its rocker. Subsequent tests with **Laker** proved that canoes with no rocker can complete a race without the paddlers needing to switch at all. Thus, GENOA's design to have a bow rocker of one inch and a stern rocker of two inches should prove to be a good balance between straight-line and turning ability.

GENOA's deepest point is positioned 74 inches from the bow, a third of the length of the canoe. It was determined that when a bow paddler is posting around a buoy, the canoe's center of rotation is near 33% of the canoe's length. Moving the deepest point forward is expected to help the canoe navigate a buoy turn by reducing the moment arm.

Two of the team's hull design goals focused on paddler ergonomics. As some paddlers sit and others kneel, it was necessary to create a rocker slope that was comfortable for either position. Prior knowledge and experience indicated that a rocker slope of one inch in height to 74 inches in length was optimal for both bow and stern paddlers. The canoe width was not to exceed 120% the span of the paddlers' hips in order to grant easy access to water, thus increasing paddler performance. This is most beneficial for the inner coed paddlers and GENOA's distinct shape, as seen below in Figure 1, shows the outcome of this goal.

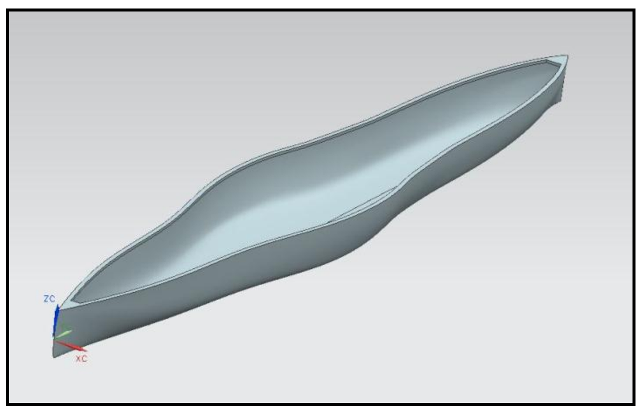

Figure 1: GENOA's unique shape.

The innovations integrated into Michigan Tech's 2012 hull design created the team's most distinguished canoe to date. Short of the canoe's weight, the team was pleased to find that GENOA met all of the design criteria during races.

STRUCTURAL ANALYSIS

The Michigan Tech Concrete Canoe Team's primary goal in the 2012 competition was to advance the analysis knowledge it had acquired during previous years. After the NCCC reinstated hull design, the team sought to make its extensive 2011 analysis applicable to different hulls.

During the 2011 competition, Michigan Tech used 73 strain gages on its 2009 competition canoe, **Polaris**, to empirically determine the stress on the standardized hull. To use this data on different hull designs, a finite element model (FEM) had to be created. An exact three-dimensional (3D) model of **Polaris** was created using Unigraphics NX7.5. This model was imported into Simulia Abaqus 6.11 where a finite element analysis (FEA) could be performed. The team's best efforts yielded a model with correct stress distributions; however, the model was off by a factor of 3.3 when compared to the empirical data.

To create outputs that were meaningful to the team, a scale factor of three-tenths was applied to all of the stresses in **Polaris**' FEA. It was determined that Abaqus was scaling the stress due to a built-in factor of safety. This hypothesis was confirmed by measuring the lateral displacement of the gunwale caps in the FEA against the data collected from **Polaris**. Once the team was convinced of the FEA's accuracy, the same procedure was used to model GENOA.

Four loading scenarios were investigated in GENOA's FEA. On the men's and coed sprint analyses, a hydrostatic force and a dynamic loading factor of 1.2 were applied to simulate the exertion force a paddler creates during a paddling stroke. In addition, the team simulated the stress on the canoe during transport and while resting on the display stands. All of the analyses were performed using an Inertia Relief boundary condition that holds the FEM in free space while the loads are applied. The tensile and compressive stresses for the four loading scenarios can be seen in Table 2. Tensile stress was the critical design parameter, as the concrete's compressive strength had a safety factor of five. The results revealed that the men's sprint was the worst-case loading scenario and is shown in Figure 3.

Table 2: Tensile and compressive stresses calculated from the four loading scenarios.

	Men's Sprint	Coed Sprint	Transport	Display Stands
Tensile Stress (psi)	342	281	37.6	49.4
Compressive Stress (psi)	350	414	23.3	117

The four loading scenarios were tested on numerous reinforcement and structural element schemes. To make changes in the FEM, the Rule of Mixtures equation was utilized to create ideal values for the reinforced concrete's material properties. The final scheme utilized a gunwale cap that reduced the stress at the top of the gunwale by 28 psi. In addition, the gunwale cap drastically increased the composite strength. The cap allowed the reinforcement to be in the proper orientation to strengthen the concrete against the bending moment created by the canoe flexing.

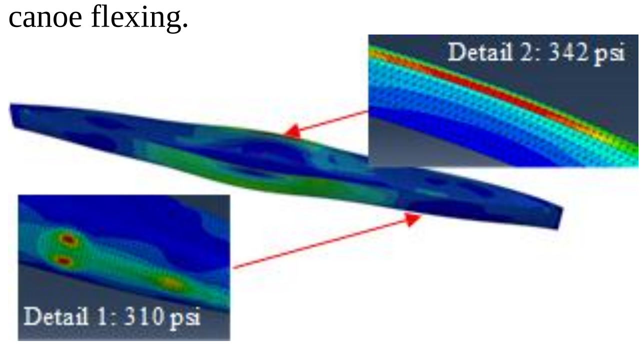

Figure 3: The FEA output of the men's sprint race. Detail 1**:** Fish-eye view of the tensile stress caused by a kneeling paddler. Detail 2: The maximum tensile stress.

Hand calculations were completed to confirm the FEA and empirical quantitative tests proved the team could reach its requirements.

DEVELOPMENT AND TESTING

This year's structural mix was designed with the objective of reducing the unit weight of the concrete while improving upon last year's tensile strength. An all-white mix was again created due to aesthetic demands. As such, the 2010-2011 mix, Kodiak, was used as a baseline. Comparative data from previous years is shown in Table 3 below. Upon receiving this year's competition rules, the team began researching new materials for the structural mix design.

The team planned to start testing during the third week of the fall semester with the intentions of casting GENOA before semester break. The original schedule called for six different mix tiers, adjusting one aspect of the mix at a time. These tiers were binders, aggregates, fibers, water-to-cementitious materials (w/cm) ratio, aggregate-to-binder ratio, and admixtures.

Due to a number of setbacks, mix design testing began three weeks late. This resulted in an accelerated mix design schedule, with testing omitting the w/cm tier. Also, only the fresh properties of the admixture tier were examined.

The team began its binder tier by testing ratios of Type I white Portland cement, vitreous calcium aluminosilicate (VCAS) grades 8 and 160 white pozzolans, and grade 120 ground granulated blast-furnace slag (GGBFS). Dark binders were eliminated from testing to meet aesthetic demands. Selection of the final binder combination was based on strength and workability.

Aggregate testing focused on reducing the unit weight of the mix. The team tested Poraver glass spheres, Extendospheres ceramic spheres, 3M K-1 microspheres, Lafarge True Lite lightweight aggregate, expanded perlite, and crushed glass bottles. Due to low strength characteristics and specific gravity concerns, perlite and crushed glass were eliminated. True Lite was dismissed due to its weight and dark color. The final aggregate gradation consisted of a blend of Poraver and Extendospheres aggregates.

Next, the team looked at loose-strand fibers in order to increase the tensile strength of the concrete mix. Previous mixes employed Nycon Kuralon RF4000 (30mm) and RECS15 (8mm) polyvinyl alcohol (PVA) fibers, which worked well. However, experience also showed that the 30mm fibers would make troweling and sanding the canoe more difficult. As such, the team tested a number of Forta nylon and polypropylene microfibers in an attempt to increase workability. Testing of the smaller-length fibers led to a decrease in workability, offsetting any gains in strength. Therefore, the team continued with the PVA fibers.

Top mixes from previous tiers were combined using various aggregate-to-binder ratios in an attempt to decrease the total amount of cementitious materials in the structural mix. This year's final aggregate-to-binder ratio was approximately 3.5:1. Due to time constraints, past experience dictated a w/cm ratio of 0.35, which was known to provide adequate workability and strength.

In order to determine the necessary admixtures, the final mix was blended using various

Table 3: Engineering properties 2009-2012.

	Name	Unit Weight (pcf)	14-Day Compressive Strength (psi)	14-day Tensile Strength (psi)
2009-2010	Kippis	53	2255	385
2010-2011	Kodiak	60.2	1026	389
2011-2012	Ballast	55.4	2112	323

combinations of Xypex Xycrilic Admix, BASF Glenium 3030 NS high-range water reducer, and BASF Delvo CRETE Stabilizer set retarder. The team then practiced troweling the test batches and selected the combination that resulted in the most workable mix.

For each batch, two 2" by 4" cylinders and four 3" by 6" cylinders were cast to test compressive and tensile strength. These tests were completed in accordance with ASTM standards after a 7 and 14-day cure. Several weeks of rigorous testing resulted in this year's structural mix, Ballast.

While the mix team was working on Ballast, the reinforcement engineering team used Kodiak to find a new reinforcement material. One of the team's main goals for this year was to find a new type of non-coated reinforcement that would not require an anchoring system to place. The team tested fiberglass, fiberglass scrim, C-Grid®, FibaCrete®, and Kevlar® materials. Fiberglass was too heavy and the fiberglass scrim had little supportive strength. FibaCrete® and C-Grid® had been used in previous canoes; both materials displayed adequate strength, but were too difficult to place on casting day.

Kevlar® 4009-1 was chosen as the team's continuous reinforcement. This material has a percent open area sufficient for the competition at 48%. The material's strength was found by taking a single strand of reinforcement and testing it in tension. Based on the cross-sectional area of the reinforcement, a minimum tensile strength of 2,980 psi was calculated. This was nearly ten times the maximum stress of 342 psi obtained from the FEA.

Using the Rule of Mixtures equation, the team determined the concrete composite strength in three-eighths inch thick concrete to be 663 psi and 913 psi with one and two layers of reinforcement, respectively. These numbers analytically proved that the stress specified by the FEA was attained by the reinforced concrete. However, the team wanted to ensure the reinforced concrete could live up to its ideal values. A cantilever beam test was created to test the strength of the reinforced concrete as it would be in a gunwale, as shown in Figure 3 below.

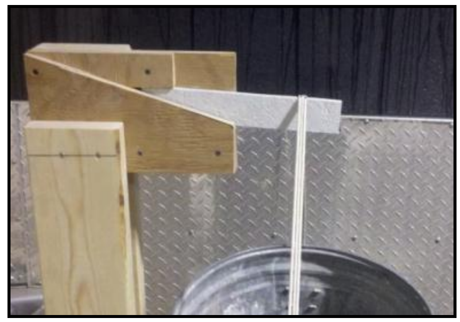

Figure 3: The cantilever beam test stand.

Three-eighths inch thick reinforced concrete plates were cut into 2" by 12" specimens for testing. Weights were applied to the specimens until the first visible crack formed, giving the tensile strength value of the composite. The Kevlar® reinforced concrete broke at 492 psi with one layer and 584 psi with two layers of reinforcement. Despite being lower than the values calculated, the obtained strength surpassed the maximum stress of the FEA. In addition, this test showed that the concrete was bonding to the reinforcement.

To empirically ensure that punching shear was not an issue for **GENOA**, two 2'-square plates were cast, one with one layer of reinforcement and the second with two layers. After curing for 14 days, the plates were individually placed on top of a foam-covered frame. A given force was then applied to each plate. The plate with one layer of reinforcement cracked but the plate with two layers of reinforcement was able to withstand the stress without the formation of any visible cracks. This indicated the canoe would need two layers of reinforcement under the paddlers.

CONSTRUCTION

The team ordered a CNC-milled, female mold made from 10% pre-consumer recycled high-density polystyrene foam. The mold was received in two sections, cut in half along the keel. Two layers of epoxy were applied to each section for the purposes of providing a stiff surface for concrete placement as well as a barrier to prevent water loss through the foam.

After the epoxy set, the sections were put together and fastened by aligning the edges and attaching the mold to a rigid frame. This can be seen in the design drawing located on page 11. Thirty minutes prior to casting, Huron Technologies Release Coating 7572 was applied to the mold; manufacturer specifications state that the release agent is designed for use between concrete and epoxy surfaces for an aesthetically-appealing result.

On casting day, the team was divided into specific assignments: seven trowelers to construct the canoe, each assigned a quality control (QC) partner to ensure proper thickness; seven reinforcement team members to guarantee proper placement of the reinforcement; and six mix crew workers to make sure the concrete was consistent throughout the day. Due to the team's facilities having separate areas for the mix and troweling groups, the team captain served as a runner between the two to encourage communication and consistency throughout the day.

During placement practices, the team tried to determine what methods worked best. A method involving hand-placed sheets of rolled concrete was found to be infeasible as it would require too much time. Thus, as in years past, trowels and hawks were used to evenly place the concrete.

New members were encouraged to learn how to trowel during troweling sessions. On casting day, the trowelers realized that the new type of reinforcement would require a slightly different technique to evenly place the mix. The chine had to be completely placed first, then up the gunwales. This meant that a horizontal movement was primarily used, rather than a vertical one.

Team members assigned to QC used premeasured depth gauges to determine the thickness of the canoe throughout its construction. However, the team soon realized that the thickness of the devices did not allow for proper measurement through the reinforcement to the mold. By using the smaller gauges and measuring individual layers of concrete instead of full depth, the team measured an initial average thickness of 0.5 inches.

From last year's extensive analysis, the team was able to determine that additional side-wall reinforcement would be unnecessary. One continuous layer of reinforcement would account for any new and unforeseen stresses, while a second layer along the bottom was for handling punching shear.

Extruded polystyrene foam was used as a placement guide for the gunwale caps on casting day. One layer of epoxy and one layer of release aid were applied to the polystyrene form. This prevented the concrete from sticking while still allowing the foam to shape to the curves of the gunwale. During casting day, these forms were clamped to the exterior of the mold, as seen in Figure 4 on page 6.

Concrete was placed by hand in the gunwale caps after the main body of the canoe was completed. The continuous layer of reinforcement in the wall was folded into the gunwale cap form. A second layer of concrete was placed, followed by a strip of reinforcement throughout the cap. Finally, a third layer of concrete was placed flush with the top of the mold.

Figure 4: Clamps holding the gunwale caps in place.

Similar sections of extruded polystyrene foam were also used for the ribs along the interior of the canoe. Loops of loose-strand carbon fiber reinforcement were added between the second and third layers of concrete to integrate the ribs into the hull, as seen in Figure 5. This was done to ensure a bond with the rest of the canoe so they would not delaminate during a race. One half of the rib was hand-placed with concrete using one of the polystyrene molds, which was then replaced with a larger mold. This too was filled by hand, then finished with a trowel for a smooth exterior.

Figure 5: Loose-strand reinforcement being integrated into the ribs.

While changes in construction methods resulted in a longer casting period, the final product possessed superior aesthetic qualities when compared to previous years. By organizing the team into specific roles and having an easier-to-place reinforcement, less people were required to be in the casting room at any given time. This was not only an important safety practice, but also a significant benefit for dividing labor requirements.

Sanding began one week after casting day. A combination of sanding and finishing continued for five more weeks after that. This combination resulted in the nominal 0.375” thickness. In the past, aluminum oxide sandpaper had been used; however, this year, the team began using carbide sandpaper. This allowed for a quicker process and lasts longer than the aluminum oxide, minimizing the amount of sandpaper required to complete the project.

Due to time constraints, recycled foam was placed in the endcaps rather than continuing intensive concrete removal in these areas. A layer of concrete was added to cover the foam.

Many hours were put into manually sanding the canoe, which can be seen in Figure 6 below. Multiple layers of finishing mix were applied to achieve a smooth finish. Extensive stain detail was used to create a beautiful appearance. After stain was applied, two layers of ChemMasters Crystal Clear-A provided the final finish.

Figure 6: Manually sanding the interior of GENOA.

PROJECT MANAGEMENT

To lead all projects on the team, junior and senior co-captains are elected to two-year terms. A safety chairperson oversaw construction tasks throughout the year. Additionally, a compliance committee was appointed to ensure all rules and regulations were met. The team was then divided into five major categories: paddling, aesthetics, engineering, technical communication, and mix design. For quality assurance purposes, the most important facets were led by experienced members of the team. Interaction between newer and older members was vital in order to ensure knowledge would be passed down, thus increasing potential for success in future years. More information is available in the organization chart on page 9.

Numerous safety applications were organized to keep safety the top priority of the team. In September, the team participated in a general safety course led by Michigan Tech's Civil and Environmental Engineering Department safety coordinator. This familiarized all team members with safety equipment, material safety data sheets, fire extinguishers, exit routes, and proper emergency contact information. The team's captains and safety chair also explained proper power tool equipment use and care. The use of personal protective equipment was stressed when performing testing and construction tasks. In addition, the team's facility and construction methods were inspected by the University Health and Safety Department as a proactive safety measure.

Material decisions occurred early in the academic year to meet analysis and design demand. However, due to poor communication and unforeseen setbacks, material acquisition was delayed. This then hindered project progress, although initial mix design testing was able to proceed with some residual materials. Table 4 shows the delays that the team encountered due to circumstances largely beyond the team's control. A two-week buffer period was built into the schedule to account for lagging tasks; sanding a week early gave the team additional working time.

Table 4: Variations in scheduling.

Task	Delay	Cause
Final Mix Selection	14 days	Poor material procurement policy, machine breakdown
Canoe Completion	36 days	Mix selection delay, setback in mold acquisition

The team was fortunate to have a majority of supplies and materials donated from affiliated sponsors. While this significantly reduced the costs for canoe design and construction, a strong emphasis remained on team fundraising. Donated materials were estimated to be $3,200, while the team has earned $15,800 through its own fundraising efforts. Registration expenses for the NCCC are estimated to be $5,000, due to Michigan Tech's large team size. The team, comprised of 25 members, holds the belief that all members who contribute deserve to attend the competition. However, travel costs are largely to be paid for by the students due to lack of funds.

Milestones were activities that completed a major segment of the project. These were determined using the 2010-2011 project schedule and are indicated with a gold diamond on the project schedule on page 10. These were met through hard work and the guidance of project managers.

The critical path was based on any activity that, if not completed by its scheduled date, would postpone completion of the entire project. These activities can be seen on the project schedule in blue. To complete these tasks, the team worked 150 man-hours designing, 300 man-hours on development and testing, 130 man-hours casting GENOA, and 500 man-hours applying finishes.

SUSTAINABILITY

This year, Michigan Tech's high aspirations were not limited to the canoe. Rather, the team worked to improve its facility by installing a water filtration system. Previously, the working area had only a holding tank of clean water on the second floor with a hose connected to a sink. Excess water was collected in buckets, neutralized as necessary, and disposed of outside. Being a gravity-fed system, the team required the second-floor tank to be refilled by University facilities' staff throughout the year.

The old system was determined to be inconvenient and non-sustainable. Therefore, a plan was drawn up to reuse water for non-mixing uses such as equipment washing.

With the new system, shown in Figure 7, grey water collected is preliminarily filtered through a screen to remove particulates. Testing determined that even the smallest size of aggregate used in the mix was removed with this set of screens. Water from this bucket is transferred to a second bucket, which acts as a settling tank where the water is allowed to sit for a minimum of 24 hours. Next, the water is pumped up by hand to a sand filter and finally a secondary holding tank. A hose from this tank connects to a second spigot on the sink, allowing team members to choose the cleanliness of the water based on its desired use.

The system also includes a connector for clean water to be pumped into the existing clean water tank without the use of a forklift. This is a major improvement in terms of safety, but also saves the team a lot of time. Eliminating the need to run a forklift every time the tank requires refilling is an additional environmental benefit of the new system.

This project was completed with a budget of $150. The system was designed to be user-friendly, low-maintenance, and compatible with future needs.

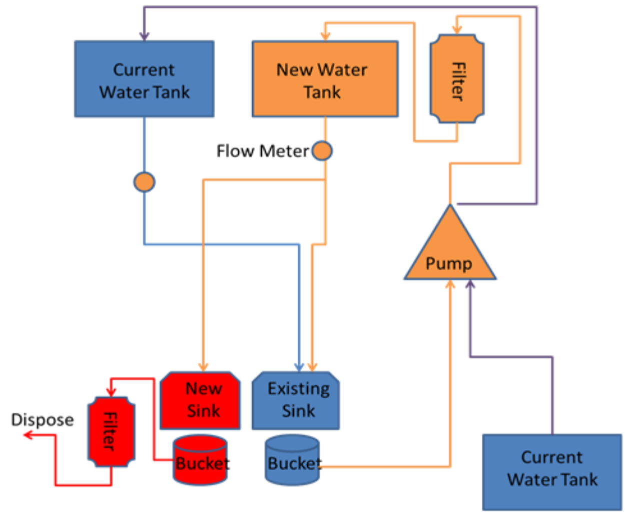

Figure 7: Schematic design of the filtration system.

Although previous years' molds had been kept for casting future canoes, the rule change allowing for hull design meant that the standardized hull from 2008-2011 would no longer be of need. While some of the polystyrene mold was used to create seats for paddlers, the rest was to be recycled into insulation. The team's advisor requested the surplus material to assist in the insulation of his basement.

The team also reused a previous year's canoe display stand to be employed in this year's cross section display. Furthermore, the particulates gathered from the filtration process are to be recast into bricks along with old concrete samples. These bricks will aid in the construction of a new pathway.

Planning and building such an endeavor took a lot of hard work, but it was embraced as a team bonding activity. This new water filtration system is easily one of the most environmentally-progressive projects the team has ever done.

ORGANIZATION CHART