Northern Arizona University

2023-2024 Concrete Canoe Team

Final Proposal

February 16^{th}, 2024

Dear Committee of the Concrete Canoe Competition,

The following document will include the Technical Proposal for the 2023-2024 Northern Arizona University Concrete Canoe Team. This report contains the development for the hull design, concrete mixture design, and reinforcement designs which are in full compliance with the American Society of Civil Engineers (ASCE) Concrete Canoe Competition Committee (C4) regulations. All relevant information including Material Technical Data Sheets (MTDS), and Safety Data Sheets (SDS) have been reviewed by the team for compliance and completeness. The team hear by acknowledges all submissions completed comply with the responses of the Requests for Information (RFI) documents provided by (ASCE). All sources of information are properly sited in the bibliography. The following students are qualified members of ASCE and meet all eligibility requirements.

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Declan Geltmacher (*he/him/his) (#000012423989)*

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Kevin Tautimer (*he/him/his) (#000012449252)*

Please contact the Project Manager, Dylan Condra, if there are any questions or concerns.

Best regards,

2023-2024 Northern Arizona University Concrete Canoe Team

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List of Abbreviations

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ASCE	American Society of Civil Engineers
ISWS	Intermountain Southwest Student Symposium
ASTM	American Society for Testing and Materials
C4	Committee on Concrete Canoe Competition
PM	Project Manager
CMDL	Concrete Mixture Design Lead
HDL	Hull Design Lead
QA/QC	Quality Assurance and Quality Control
Ft	Feet
In	Inch
Ksi	Kips per square inch
Psi	Pounds per square inch
Pcf	Pounds per cubic foot
Cf	Cubic feet
NAU	Northern Arizona University
RFI	Request for Information

1.0 Executive Summary

Flagstaff Arizona stands at 7000 feet in elevation surrounded by the world's largest ponderosa pine forest, and five mountains including the famous San Francisco Peaks. The Northern Arizona University competitive capstone students are deeply passionate about our pristine town and exceptional university, our passion inspired our decision to show our school spirit and unified senior class by naming ourselves after our school mascot the Lumberjacks. The PaddleJacks, SteelJacks, and TimberJacks will compete in their respective projects at this year's Intermountain Southwest Student Symposium (ISWS) competition. The Northern Arizona University's Paddle Jacks strive to achieve first place at the ISWS Concrete Canoe Competition with the USS Pinecone. Our team is determined to continue NAU's fantastic track record and are proud to represent our American Society of Civil Engineers (ASCE) student chapter. Previous Concrete Canoe teams such as 2022 Pinecone team scored an impressive 2nd place overall, and the 2023 Canoe Captains scored 4th place which leaves giant shoes for the 2024 Paddle Jacks team to fill. Designing, constructing, and racing a structurally sound, and environmentally sustainable vessel is no easy task.

Our team utilized several innovative strategies such as reusing or repurposing previous years teams' equipment such as the concrete curing chamber, reusable pouring table, and leftover Styrofoam which was used to fill the bulkheads. Several software programs such as Excel, Solidworks, and AutoCAD, were used to analyze the canoe hull for structural integrity, buoyancy, and simplify the construction processes. The use of this software drastically reduced the time for creating cross sections for the manufacturer to carve out the Styrofoam mold. The symmetrical design of the canoe allowed the manufacturer to carve out two cross sections at a time with a computer numerical control, CNC, and hot wire machine which cut the production in half. After the construction of the canoe, the Styrofoam mold is reused as a protective barrier for transportation and storage purposes.

The concrete mixture design utilizes local and unique alternative materials, which ensures a balance of buoyancy, strength, and lighter density. This result provides a lighter, faster canoe that complies in accordance with ASCE standards. Primary carbon fiber reinforcement and secondary fiber reinforcement provide a higher tensile strength, and crack resistance substance which reduces the risk of failure and cracking during the construction process. The designs account for the leftover materials from previous years' canoes to minimize waste, and cost of production. Table 1 shows the average concrete mixture properties and the (ASTM) test that was conducted.

Table 1: Concrete Mixture Properties

Concrete Mixture Properties		
Property	**Value/ Units**	**ASTM Standard**
Compressive Strength (14-day)	1010 psi	ASTM C39 [3]
Tensile Strength (14-day)	140 psi	ASTM C496 [4]
Composite Flexural Strength (14-day)	172.6 psi	ASTM D8058-19 [1]
Plastic Unit Weight	66.8(lb./ft^3)	AASHTO T121 [6]
Oven Dry Unit Weight	54.6 (lb./ft^3)	AASHTO T121 [6]
Slump	2 in	ASTM C143 [2]
Air Content	1.0%	AASHTO T121 [6]
Reinforcement		
Primary	CSS-BCG Bidirectional Carbon Grid	
Secondary	Master Fiber M 35	

The concrete canoe's hull was designed to be stable, fast, and maneuverable all while being able to hold and support four people during all rowing maneuvers. The final hull design is a straight keel line canoe which has a shallow arched bottom which compromises the performance, and the stability of the canoe. The hull sides are flared to promote stability and increase the tip resistance. The bow of the canoe has a moderate recurve and a high entry angle for ease of construction and to properly support multiple passengers. The final canoe hull properties are seen below in Table 2.

Table 2: Canoe Hull Properties

Property	Value/ Units
Length	18ft
Maximum Width	32 in.
Maximum Depth	16 in.
Thickness	.5 in.
Estimated Weight	180 lbs.

2.0 Project Delivery Team

2.1 ASCE Student Chapter Profile

Northern Arizona University's American Society of Civil Engineers Student Chapter currently has around 30-40 active members comprised of students of all grades. The NAU chapter has 11 officers and is led by our team captain Dylan Condra who is the acting ASCE Student Body President. The goal of NAU's student chapter is to expand students' personal and professional connections to help students succeed in school and after graduation. This is achieved through in-person meetings once a week with team building exercises such as ice breakers to meet other fellow students, regular guest speakers of engineering companies to encourage internship opportunities and expand the technical understanding of engineering work, and extracurricular activities such as hiking, ice skating, movies, and other team bonding opportunities. The student chapter hosts an annual golf tournament fundraiser at Flagstaff Ranch golf course to raise money for activities and conferences during the semester. In addition, the student chapter is committed to the community by conducting trash clean up along Plaza Way in Flagstaff and outreach to K-12 through an event called STEM City. ASCE also holds some meetings each semester dedicated to resume building, in which students can connect with professionals and faculty to gain valuable information. NAU's ACSE chapter creates a welcoming atmosphere encouraging students of all students to participate in competition events like the Intermountain Southwest Student Symposium (ISWS). The competitions we compete in are surveying, environmental design, steel bridge, timber strong, transportation, technical paper, sustainable solutions, and construction. These are in addition to the concrete canoe competition.

2.2 Key Team Roles

The team is comprised of four key members: Dylan Condra, Declan Geltmacher, Kevin Tautimer, and Derek Vecchia.

The team roles have been divided into the following roles: Project Manager, Concrete Mixture Design Lead (CMDL), Hull Design Lead (HDL), Structural Design Lead (SDL), and Quality Assurance and Quality Control Lead (QA/QC).

Dylan Condra, the Project Manager (PM), is responsible for the team's organization, project schedule, finances, fundraising, and assistance to other roles when required. Dylan oversees all ongoing to ensure deadlines will be met, within budget, and the deliverables are within the guidelines and meet all requirements.

Declan Geltmacher, The Concrete Mixture Design Lead, is responsible for all material research, concrete mixture design, reinforcement design, and testing of all samples. Declan will supervise mentees during testing or strenuous tasks.

Kevin Tautimer, the Hull Design Lead, and Structural Design Lead, is responsible for researching and designing the hull of the canoe and completing all required structural calculations. Kevin ensures that the canoe meets all requirements, is structurally sound, and optimizes the hydrodynamics of the canoe.

Derek Vecchia, the Quality Assurance and Quality Control Lead, is responsible for ensuring all work completed by the team meets all regulations and rules in accordance with ASCE. Derek oversees all mixing, and testing done by any key member ensuring a high-quality product that is completed safely and in accordance with ASTM testing procedures.

3.0 Organizational Chart

Dylan Condra (Sr.)
Project Manager

Declan Geltmacher (Sr.)
Mixture Design Lead

Derek Vecchia (Sr.)
(QA/QC) lead

Kevin Tautimer (Sr.) Hull Design and Structural Design Lead

2023-2024 Mentees:

Jessica Hillman

Kylie Hanson

Trevion Booker

ASCE Faculty Advisor:

Mark Lamer, P.E.

4.0 Technical Approach to Project

4.1 Hull Design

The main goal for this year's concrete canoe was to have a stable canoe for competition. After reviewing many past reports from previous years, it was decided that the canoe must focus on maneuverability and stability. With this, extensive research was done on the different shapes of canoes to find out the advantages and disadvantages of each hull.

Although an asymmetrical canoe is faster, the team decided to go with a symmetrical canoe for ease of mold manufacturing and constructability. The symmetrical canoe allows us to analyze our canoe to easily predict what it will do. After extensive research, it showed that the shallow arch canoe had the advantages of a round bottom and a flat bottom without gaining their disadvantages. With the design of a shallow arch canoe, a V-shaped bow and stern to help its agility.

The canoe's draft was created in SolidWorks to run a preliminary analysis on it using the software. Through research, it was found that a long canoe would not be efficient for maneuverability. Considering this, the canoe's hull length is 18 feet, and the widest part reaches 32 inches. The canoe's depth was chosen to have a maximum of 16 inches to help with the freeboard during load applications.

4.2 Structural Design

The concrete canoe was structurally designed with three main criteria. These being a high compressive stress, high tensile strength from our reinforcement, and the lightweight of the mix design. The compressive and tensile strength were expected to be able to withstand the four-paddler load being applied to it. It was also expected that the lightweight concrete's density was sufficient to allow the canoe to be buoyant and float without the use of Styrofoam-filled bulkheads.

The structural analysis calculations were performed for the two-person loading since it was decided that the locations for the max shear and moment would not change. The calculations utilized principles of statics and reinforced concrete design to create shear force and bending moment diagrams. The canoe was analyzed using three primary forces: self-weight, buoyancy, and point loads representing our paddlers. The canoe was modeled as a continuous support beam as buoyancy reactions act on the whole canoe.

For the two-male sprint caseload, point load magnitudes were chosen to be 175 lbs. based on the average weight of the males on the competition team. These point loads were placed a quarter into the canoe from the ends. To represent our dead weight, we calculated the weight using SolidWorks software using the 3D model which came out to be 190 lbs. The value was then divided by the length of the canoe to get the distributed load in the direction of gravity. The buoyancy reaction was calculated by adding the load reactions. This value was calculated to be 350 lbs., which was calculated by finding the reaction forces of the canoe. The loading was 175 lbs. for each person.

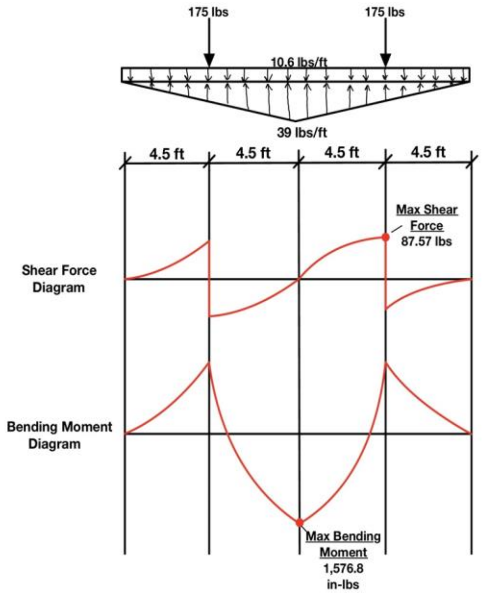

Figure 1: Free Body Diagram w/ Shear Force and Bending Moment

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A shear force and a moment diagram were created from the two male-tandem load cases. The maximum shear force for the load was found to be 88 lbs. and the maximum moment was found to be -1,576.9 in.-ft. The maximum locations for both shear force and moment are highlighted in the diagrams shown above.

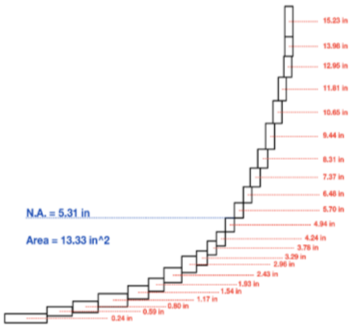

Figure 2: Moment of Inertia Rectangles

The cross-sectional analysis was done to find the centroid of the canoe and the moment of inertia for the widest part of the canoe. This was done by creating 22 rectangles that very closely resembled the canoe. The centroid of the canoe was found to be 5.3 inches from the bottom of the canoe. Then the parallel axis theorem was used to calculate the moment of inertia which was found to be 1363.72 in^4. Given the centroid of the canoe, extreme fiber distances for both compressive and tensile were found. The extreme fiber distance for compressive was calculated to be 5.3 inches from the bottom of the canoe and the tensile distance was 10.6 inches from the top. Since the canoe was determined to have many risk factors, the Safety Factor was determined to be 3.5. The main reason for such a drastic number is to try to limit as many unpredictable errors as possible. Since it's a concrete canoe, there are many factors that play in making it float and tread water. To minimize the risk of error, our Safety Factor was high to incorporate the unforeseen errors that could occur.

To structurally analyze the hull, the flexural and punching shear capacity is compared to the demand from the applied loading. Table 3 lists a summary of these values. Complete calculations are provided in Appendix C – Structural & Freeboard Calculations.

Table 3: Demand Vs. Capacity

	Demand	Capacity
Punching Shear (psi)	9.7	65.7
Moment (lbs.-ft)	131.4	5,999
Buoyancy Freeboard (in)	2.31	>0

The canoe was analyzed as a two-way slab. The punch shear was calculated using the 3x3-inch square area to simulate the area underneath the paddler's knee. The values calculated for shear, moment, and punching stress are all demand values. Meaning that these values are what the canoe exerts with the specific loading case. The demand and capacity are very different in the aspect of failure. The capacity value is the value that the canoe can withstand without failure. If the demand exceeds the capacity, the canoe will automatically fail due to the force being greater than what the canoe can withhold.

The final step in the structural analysis was to assess the worst-case compressive and tensile stress against Mohr's failure envelope of compression and tensile strengths of the mix. The two-person loading maximum compressive state was calculated to be 21.5 psi and the maximum tensile state was calculated to be 43.24 psi. The compressive and tensile strength were determined via strength testing. The compressive strength was determined to be 1000 psi and the tensile strength was 140 psi. As shown in figure 3, if the maximum tensile and compressive stress are assumed to occur at a single point (conservative), this fictitious and worst-case state of stress lies within Mohr's failure envelope. Thus, the strength of the canoe is adequate.

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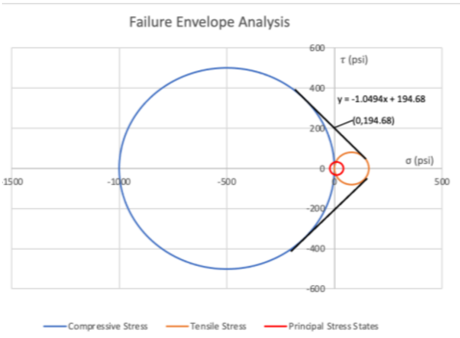

Figure 3: Failure Envelope Analysis

4.3 Mix Design

The main goals for the concrete mixture design were to use available material from previous years' teams at the school's facility and create a competitive and viable mix design that follows and abides by the 2024 Concrete Canoe Request for Proposal for aggregates and materials. The summary of the mixture designs can be found in Table 4. Reading the table, all cementitious materials are the type 1 cement, fly ash, grade 120 slag, and type s lime. All aggregate are aero aggregate, PC4, red sand, K1 glass bubbles, and poraver. The recycled by products are grade 120 slag and fly ash class F. To construct an optimal design the team reflected on previous years' mixture designs and other sources of information to determine what makes effective and non-effective mixtures. Notable methods were reused in the teams' mixtures while maintaining unique portioning of materials and new aggregate supplements from local sources which created multiple mixtures that were durable, light, and abided by the rules and regulations of the competition. The reused and locally sourced materials used ensured a cost-effective prototype that supports local businesses.

Table 4: Mix Design Table

Materials	Mix 1 (ft^3)	Mix 2 (ft^3)	Mix 3 (ft^3)
Calport Type 1 Cement	0.76	0.76	0.76
Fly ash Class F	0.71	0.71	0.71
Slag Grade 120	1.16	1.16	1.16
ChemStar Type S Lime	3.63	3.63	3.63
MasterFiber M3	0.04	0.04	0.04
Aero Aggregate	8.71	8.71	8.71
PC4	0.54	0.40	0.40
Red Sand	1.61	0	0
K1 Glass Bubbles	2.35	3.06	0
Poraver	0	0	5.72
Water	4.89	4.89	4.89
Air	2.6	3.64	0.09
Total	27	27	27
Mix Properties			
Compression Strength (psi) 14 day	1010	660	1890
Tension Strength (psi) 14 day	140	100	220
Wet Density (lb./ft^3)	69.8	60.1	70.6
Dry Density (lb./ft^3)	43.5	41.6	54.6
Air Content (%)	1.0	1.4	0.3
Slump (in)	2.0	1.9	3.0

The cementitious materials used consisted of Type 1 cement, Fly Ash Class F, Grade 120 Slag, and Chemstar Type S Hydrated Lime. The cement, fly ash, and slag were obtained from Salt River Material Group and Cemex both operating and locations being in Arizona.

The type 1 cement has a specific gravity of 3.15 and was selected due to the competition location not having any sulfur or sulfates to damage the concrete. This is the primary bonding and gives overall strength to the mixes.

The fly ash was used to replace 20% of the cement used in the mix. Because of its properties to decrease permeability of the concrete and long-term strength it was chosen. The fly ash has a specific gravity of 2.75 allowing mixes to be replaced by cement with a lighter material.

Grade 120 Slag was used to replace 35% of the cement. Due to its property of long-term strength gain

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and having a specific gravity of 2.95 would allow for a stronger mix and lighter material to be used in all mixes.

Chemstar Type S hydrated lime was chosen as it was allowed in the 2024 Concrete Canoe Request for Proposal. The hydrated lime meets ASTM C207 and has a specific gravity of 0.55. Because the hydrated lime is an air retarder and a water reducer it was chosen so admixtures aren't required in any of the designs. 20% of the cement was replaced with hydrated lime to reduce the amount of cement used.

With respect to the 2024 Concrete Canoe Request for Proposal, "Any natural, manufactured, or recycled aggregate is permitted" [3] if aggregate sieve analysis is conducted through ASTM C136 and the total aggregate volume meets 30% of any of the concrete mixes.

Material research showed several aggregates that abide by the rules and regulations for the mixture design ranging from Aero aggregate, Perlite, Utelite, coffee grounds, red sand, Post Consumer Carpet Calcium Carbonite, K1 glass bubbles, and Poraver. The Utelite was too heavy compared to the Aero and after comparing results on concrete testing there wasn't a notable difference between the two. After researching coffee grounds, there was a greater margin of error that in creating suitable aggregate was too time-consuming. The materials that were selected for the mixtures were Aero aggregate, red sand, Post Consumer Carpet Calcium Carbonite, K1 glass bubbles, and Poraver.

Ul-FGA, Aero aggregate is created from 99% recycled glass. It is a very porous material that has an absorption of 40.5%, a specific gravity of 0.41, and a moisture content of 0.16%. The properties of this material allow larger quantities without the risk of it becoming too dense. The rules removed graduation requirements which allowed larger aggregate sizes from $^1/_2$ to $^3/_8$ which created a stronger mixture overall.

Red cinder sand is locally sourced in Flagstaff and is a natural product from the surrounding cinder hills. It is a porous material that has an absorption of 2.8%, a specific gravity of 1.987, and a moisture content of 2.16%. Locally sourcing the materials for our project encourages local businesses, and it is lighter than normal sand which resulted in a lighter mix.

Post-Consumer Carpet Calcium Carbonite is a recycled aggregate from carpet. It acts as little fibers in the mix mixes in small gaps that larger aggregates cannot fill. It has been used in previous years and has shown to have impressive results. It has a specific gravity of 1.33, absorption of 40.0%, and moisture content of 0.5%.

K1 Glass bubbles are glass micro balloons that are very water and oil-resistant. They are used in underwater construction and fill in very tight spaces. Due to these properties along with it being a very small aggregate it was chosen. K1 glass has an absorption of 0.0%, specific gravity of 0.35, and moisture content of 0.2%.

Poraver is 100% recycled glass and can absorb water. From testing samples, it is stronger than the K1 glass bubbles but is heavier due to being able to absorb water. It has a specific gravity of 0.06, absorption of 35.0%, and moisture content of 3.16%.

Table 5: Fine Aggregate Gradation

Sieve (% Passing)	Aero	Red Cinder	Carpet	Poraver	K1 Glass
4.75mm (No.4)	48.1	99.8	98.2	100	100
2.36mm (No.8)	7.0	95.9	96.3	100	100
1.18mm (No.16)	1.8	66	83.6	100	100
600um (No.30)	1.8	44.9	64.1	100	100
300um (No.50)	1.8	25.4	37.6	95.9	96.9
150um (No.100)	1.7	8.0	16.5	17.3	41.2
75um (No.200)	1.4	4.1	6.25	1.3	29.2

Following ASTM C136 each aggregate used had a sieve analysis conducted in which the team was able to see how well graded our aggregates were. These gradations can be seen in Table 5: Fine Aggregate Gradation.

The concrete mixture design process began with extensive background research from multiple sources such as textbooks, instructors, and previous years' research. The textbook used is Design and Control of Concrete Mixtures [4] which was used to create all mix designs for the client. From the text, the team selected a maximum water-to-cementitious material ratio of 0.50

which gave the concrete low permeability when exposed to water which allowed the canoe to resist absorbing water when competing. This cm/w ratio was then checked for compliance in accordance with the rules. A required average compressive strength of 1,640 psi was selected using Design and Control of Concrete Mixtures [4], concrete strength tables. The bulk volume of coarse aggregate was selected from tables in Design and Control of Concrete Mixtures [4] to determine how much coarse aggregate is used. This was accomplished by taking in the coarse aggregate partial size that was required to fit between the carbon fiber mesh used as the primary reinforcement for the canoe with open-air spacing of ½” and then using the fineness modulus of the fine aggregate we will be using the main fine aggregate which was 2.82 for the red cinder sand. From the hole size of ½” and fine modulus of 2.82 we were able to bulk volume of 0.46 per unit volume of concrete. The target air content for the concrete mixes depended on whether the mixture had air entrainers, and with the maximum aggregate size of ½” the target air content was 2.5%. The water content of the mixes came from Table 13-8B [4] in which using the maximum aggregate size of ½”, non-air-entrained concrete column, and using a target slump of 1-2” the water content for cementitious materials is 350 lbs. Factoring in that the aggregate we are using is gravel-like with some crushed particles we can reduce by 45 lbs. leaving us with 305 lbs. of water.

Creating and testing the mix designs showed different strengths and weaknesses the materials have and showed how through in-cylinder testing. Due to time constraints and the unpredictability of concrete testing as a team, we tested 3 cylinders for compression and 2 for tension with a 14-day break, Should the batches not have worked the team would have had to create and test another few batches of new mixes. Due to this and carefully reading through ASTMs C39 [5], C469 [6], D8058-19 [1], C143 [2], and AASHTO T121 [7]. The quantities of samples and their respective test with documents in Table 5, and quantitative test results of them from each mix with properties can be found in Table 6.

Table 6: Concrete Testing Table

Concrete Testing		
Test	ASTM/AASHTO	Sample
Flexural Strength	ASTM D8058-19 [1]	10 per chosen mix
Tensile Strength	ASTM C496 [4]	2 per design
Compression Strength	ASTM C39 [3]	1 per design
Air Content	AASHTO T121 [6]	1 per design
Density	AASHTO T121 [6]	3 per design
Slump Test	ASTM C143 [2]	1 per design

The deciding factor for the main reinforcement chosen was trends from previous years. This showed the usage of carbon fiber reinforcement had high success rates and ultimately was chosen for the main reinforcement. The secondary reinforcement chosen was called MasterFiber M 35, which is used in the concrete mix to control the cracking when curing.

The carbon fiber mesh is CSS-BCG Bidirectional Carbon Grid. The material properties of an ultimate tension strength of 9.5 kip/ft and a weight of 3.9 oz/yd^2. After testing the mesh using ASTM A1067-10 [9] the tested average strength was 100 psi. The testing equipment used is not ideal for the application of testing the strength of our reinforcement. Using the reinforcement along with mix 1 to create test specimens for ASTM D8058-19 [1] testing the composite strength of our canoe. The results were a flexural strength of 172.6 psi. The applications of the mesh are to be used for load ratings, damage repairs, blast control, and defect remediation. The properties of load ratings and defect remediation will help with the strength and in the construction process. The MasterFiber M 35 meets ASTM D 7508 and is used to reduce the plastic shrinkage of concrete curing. It has a specific gravity of 0.91 and a tensile of 30 ksi.

Table 7: Reinforcement Table

Reinforcement Flexural Strength	CSS-BCG
Reported (psi)	0.1
Tested (psi)	100
Composite (psi)	172.6

For the team to choose a mix design for the protype, an in-depth decision matrix was created. The decision matrix was created with several criteria with respective weighting percentages. The criteria for the concrete mixture design are as follows: dry density weight, Compressive strength, tensile strength, workability, cracking, and renewability. Each mixture was then given a value of 1-3, 3 being the most effective, and 1 is the least effective. Table 9 seen below shows the final decision matrix in which mixture 1 was the best option.

Table 8: Mix Decision Matrix

	Weight		Design #1	Design #2	Design #3
Dry Weight	30%	Score	2.87	3	2.1
		Weighted Score	0.86	0.9	0.62
Compression	25%	Score	2.7	1	3
		Weighted Score	0.68	0.25	0.75
Tension	25%	Score	1.9	1.4	3
		Weighted Score	0.47	0.34	0.75
Workability	10%	Score	3	2	1
		Weighted Score	0.3	0.2	0.1
Cracking	10%	Score	3	1	2
		Weighted Score	0.3	0.1	0.2
Green	5%	Score	2	3	1
		Weighted Score	0.1	0.15	0.05
Weighted Total			2.71	1.94	2.47

4.4 Construction Process

The mold constructed is a female 1.5 lbs. density EPS Styrofoam mold, which was cut by a CNC hot wire machine and took approximately 10.5 hours to cut a total of 58 four-inch cross sections. This material was recommended by the manufacturer for being lightweight, moderately resilient, and easy to work with. The female mold was selected for the benefits of reduced cracking during the curing process, ease of construction, reusability of storage, and transportation protection. The 58 four-inch sections were glued with a polyurethane construction adhesive and carved out with a hot wire knife and sanded down till completely smooth. As seen in Figure 4, a liquid rubber substance was applied to the cut-out section of the

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Figure 4: Application of Releasing Agent

The team secured the mold to a reusable construction table left over from previous years for accessibility and ease of pouring. The final concrete solution was mixed in several 5-gallon buckets while the primary carbon fiber reinforcement was cut to size. The team used a layering approach to pouring the concrete mixture to easily ensure quality, and consistency, and reduce time. The first layer of concrete was applied to the inside of the mold till an even distribution of ¼ inch thickness was reached on all sides which was confirmed by the (QA/QC) lead. In Figure 5, the team then set the carbon fiber mesh, adjusting to any imperfections.

Figure 5: Primary Reinforcement Placement

Finally, the last layer of the mixture is applied and evenly distributed across the primary reinforcement. Once confirmed to be ½ inch on all sides by the (QA/QC) lead, the construction of the bulkheads can begin, learning from the mistakes of last year's canoe team, a cardboard pouring frame was constructed to control the thickness of the bulkhead walls. Once the frame has been placed and the dimensions have been confirmed, the inside of the bulkhead is carefully filled with leftover Styrofoam from the sanding process as seen in Figure 6 below.

Figure 6: Bulkhead Construction

After each bulkhead is filled to the appropriate level, the concrete mixture is applied to the frame. The team constantly observed for uneven areas, and cracks, attempting to get the canoe as smooth as possible. The Curing Chamber, as seen in Figure 7, is made of PVC pipes, plastic liners, and humidifiers which were reused from the previous year's team. This was reassembled on top of the construction table and wrapped with the plastic.

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Figure 7: Curing Chamber

The canoe will then undergo a series of curing processes, immediately after the pour the canoe will stay in the curing chamber for 14 days with the humidifiers constantly running. The Curing chamber will then be removed, and the canoe will sit for 7 days in a humid room. Finally, the canoe will cure in a dry location for an additional 7 days for a total of 28 days to achieve the highest possible compressive and tensile strengths. Once the Canoe has properly cured for 28 days the mold will then be removed in sections to reduce risk. Once the canoe has been removed, several layers of sealant will be applied to the exterior of the canoe along with the Northern Arizona University Sticker and Canoe name. After the Sealant has cured the inside of the canoe will be sanded down for the comfort and safety of the passengers.

4.5 Health and Safety

The health and safety of the team and others (such as mentees) will be outlined in the safety document the team created to ensure that proper tool usage and chemical safety are executed. Safety will be paramount in the work conducted at any given time. Under any condition that unsafe safe conditions are presented, appropriate action will be executed if an incident were to occur, the team would call the police department/paramedics and notify the lab manager, Dr. Adam Bringhurst. In the safety binder, links to videos demonstrating how to use tools properly and safely such as power drills, various types of saws, aggregate crushers, sieves, etc. Each chemical and material has a supplied SDS sheet readily available in case of injury and easy diagnosis of exposure. In addition, a mitigation plan was created between the team and the college's Environmental and Health Services. This targets and mediates the risks of using tools, chemicals, and other hazardous conditions during construction. The building's ventilation is addressed to be open during the operation where fine particulates from the Styrofoam, chemical fumes, sawdust, and/or carcinogens like silica in the materials. The risk of pinch points from tools is addressed by placing the tool in the correct position, using proper personal protective equipment (PPE), and the safeguards on the tools. lifting of heavy objects is limited to 30 lbs. with one person. Anything above will require additional people or equipment such as a dolly to move. The safety binder will be a physical copy in a three-ring binder in the workstation and be required to be read by anyone who has not been to the workstation previously.

4.6 Research and Development Cost

The Project manager Dylan Condra is responsible for the projects' funding. Dylan works with the ASCE student chapter treasurer to fundraise and manage the funds. The team estimated the required funds required to complete the project, which is seen in Appendix F. The cost analysis is divided into 3 main categories such as Personnel, Travel, and Manufacturing costs. Research of designs for mix design and hull design came from a variety of sources. The majority were learning from the previous year's designs and improving the materials for increased buoyancy or overall performance of the canoe. By consulting with the designers over the years, new ideas were created and implemented into the mix design and hull design. The research of materials for concrete mix designs was found by contacting a vendor (Alyson Ayres from CalPortland) who assisted with last year's project. She was able to give us recommendations regarding materials locally and different connections to other vendors. Most of the materials we plan to utilize have been donated by the companies directly to us. Materials such as the grade 120 slag, class F fly ash, Aero aggregate, red sand, and others we decided not to use. Research for hull design started with consulting our technical advisors, and the 2022-2023 team immediately gave parameters of viable options, the team narrowed down the final design to the desired performance results.

4.7 Quality Control and Quality Assurance

Quality assurance is defined as the ability to ensure the final product is produced with the correct techniques and procedures. By reading the ASTM sheets and referring to the rules provided, quality can be further controlled. Quality control is defined as checking the product during the construction phase and verifying no errors or mistakes have occurred. By designating Derek Vecchia as the (QA/QC) lead his job will be to stay informed at all times of the type of work and how to aid critical issues that arise. Constructing a quality product with the least number of errors possible reinforces the mitigation of failures and repairs that would be required. Some errors could include the cracking or chipping of concrete, improper texturing of a surface, and incorrect pouring techniques and practices. The team believes adequate communication is key for success, routine meetings before any task were implemented to discuss desired results, and proper methods would identify, and explain how to address issues. Referring to standard procedures when required, and learning from previous years' successes, and mistakes.

(QA/QC) measures were taken at all points of the entire project. The scope and schedule were created to account for potential delays due to external factors, overlapping projects, and even distribution of work allowing the team to comfortably finish the project with time to address unforeseen issues that arose. The mixture and hull design mitigated risk by researching (ASCE) regulations and primarily using local or left-over materials to reduce the risk of delivery setbacks. All non-local or depleted materials were the priority and acquired as early as possible.

To ensure the quality and safety of the concrete mixture testing, all testing is done with a minimum of two people at any given moment. All data is properly stored in a location where all members have access. Testing adheres to all ASTM and NAU rules and safety procedures. Hull designs and calculations shall be stored in a shared location of all members and the final designs approved by the Technical Advisor and key team members.

The construction phase has several (QA/QC) procedures for all steps of fabrication. While assembling the mold, risk mitigation techniques were taken for future tasks, such as the liquid rubber releasing agent applied to the mold before pouring. During the pouring of the canoe, a layer pouring technique with a pre-determined method of measuring the thickness of concrete shall be used to produce a high-quality canoe minimizing gaps, and the uneven thickness of the walls.

4.8 Sustainability

The concrete canoe was produced using materials accumulated from previous competitions and recycled materials. One of the materials is PC4, known as Post Consumer Carpet Calcium Carbonite. It is a recycling by-product that comes from carpet backing. Being able to use this byproduct in concrete helps in improving the material's uses after its original purpose. Aero aggregate is made of recycled crushed glass. Its process is from recycling bottles and other glass products into a foam which is then broken into pieces. It gives new life to potentially now unrecyclable products such as glass. After concrete test pours and the final canoe pour, the procedures of recycling wasted concrete will be enacted. By waiting for the concrete to solidify, the concrete will be stored in buckets and taken to a local landscaping company where the concrete will be reused as recycled concrete. At the end of manufacturing the canoe, the Styrofoam mold will be hauled to an approved recycling center. Consideration of potential environmental impact and the preservation of materials should be encouraged and promoted.

5.0 Construction Drawings

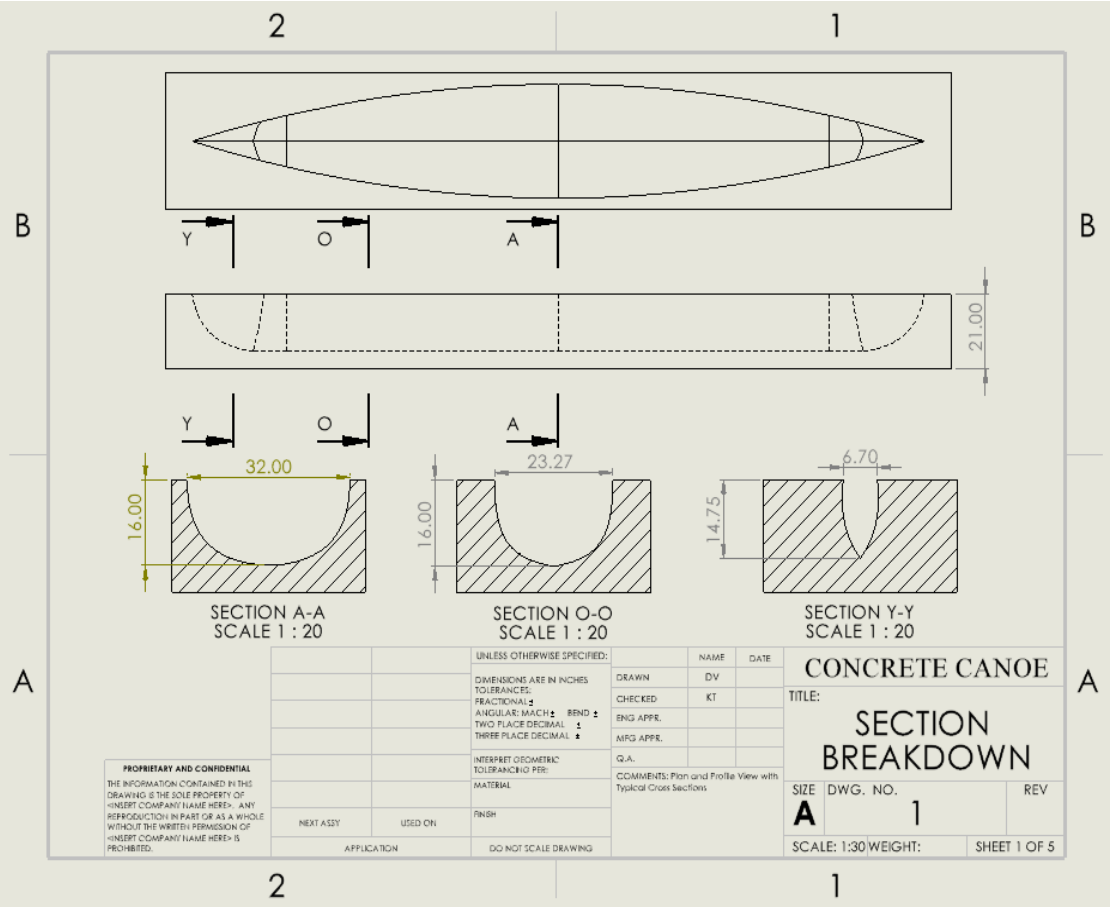

Figure 8: Canoe Mold Section Breakdown

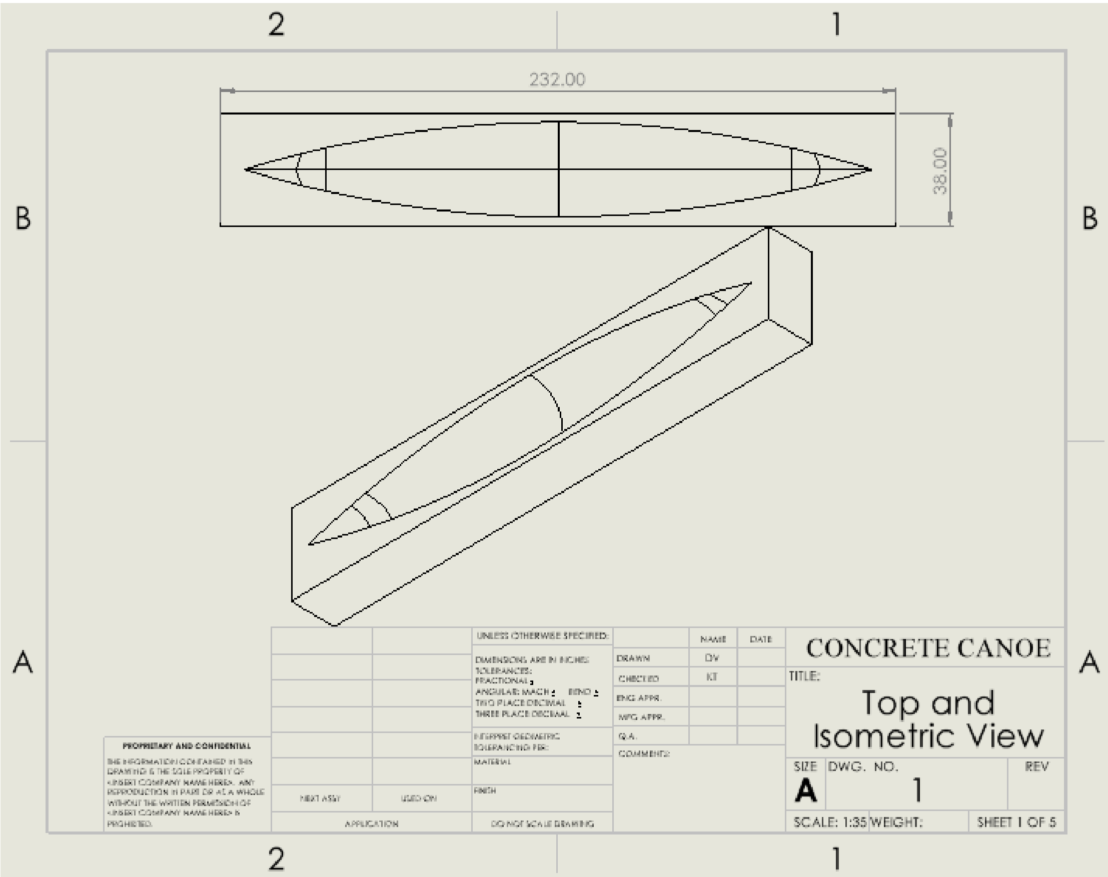

Figure 9: Top and Isometric View

6.0 Project Schedule

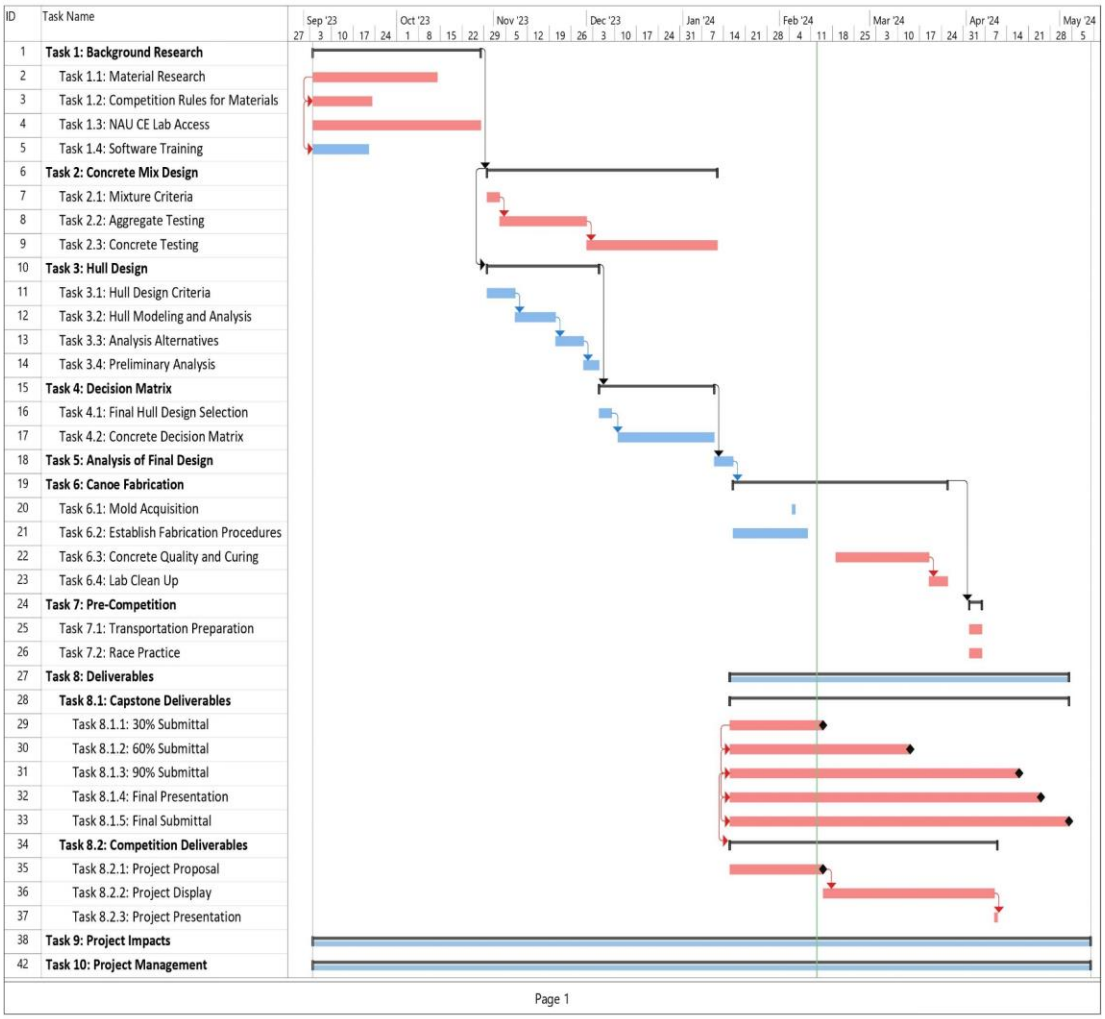

Figure 10: Project Schedule

Appendix A -Bibliography

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Appendix B – Mixture Proportions and Primary Mixture Calculations

Equation 1: Absolute Volume

$$Absolute\,Volume = \frac{mass}{(Sg\ x\ 62.4)}$$

Sg= Specific Gravity

$mass$= mass of substance

Equation 2: Water

$$Water = \frac{W}{cm} X\ cm$$

$\frac{W}{cm}$= Water to cementitious material ratio

cm= cementitious material

Equation 3: Batch Water

$$w_{batch} = w - (w_{free} + \sum w_{admix})$$

w_{batch} = Batch Water

w= Water

w_{free}= Free water from aggregate

w_{admix}=Free water from admixture

Equation 4 : Moisture Content Total

$$Mc_{total} = \left(\frac{W_{stk} - W_{od}}{W_{od}}\right) X\ 100\%$$

Mc_{total}= Moisture Content Total

W_{stk}= Stock weight

W_{od}= Oven dry weight

Equation 5: Free Moisture Content

$$MC_{free} = Mc_{total} - A$$

MC_{free}= Free moisture content

Mc_{total}= Moisture Content Total

A=absoription

Equation 6: Free Water Content

$$w_{free} = W_{od} x \left(\frac{MC_{free}}{100\%}\right)$$

w_{free}= Free Water Content

W_{od}= Oven dry weight

MC_{free}= Free moisture content

Equation 7: Volume of Water

$$Volume_{Water} = Mass_{water}/62.4$$

$Volume_{Water}$= Volume of water

$Mass_{water}$= Mass of water in mix

Equation 8: Mass of Concrete

$$M = Amount_{cm} + Amount_{fibers} + Amount_{aggregate} + Amount_{water} + Amount_{solids}$$

$Amount_{cm}$= cementitious material total weight

$Amount_{fibers}$= fibers total weight

$Amount_{aggregate}$= aggregate total weight

$Amount_{water}$= Water total weight

$Amount_{solids}$= Solids Total weight

Equation 9: Absolute Volume of Concrete (v)

$$V = Volume_{cm} + Volume_{fibers} + Volume_{aggregate} + Volume_{water} + Volume_{solids}$$

$Volume_{cm}$= cementitious material total volume

$Volume_{fibers}$= fibers total volume

$Volume_{aggregate}$= aggregate total volume

$Volume_{water}$= water total volume

$Volume_{solids}$= solids total volume

Equation 10: Theoretical Density (T)

$$T = M/V$$

T= Theoretical Density

M= mass

V= Volume

Equation 11, Air Content

$$Air\ Content = \frac{T - D}{T\ X\ 100}$$

T= Theoretical Density

D= *Measure Density*

Equation 12: Air Content Absolute Volume Method

Air content $= (27 - \mathrm{V})/27$ x 100

V= *Volume*

Equation 13: Cement-Cementitious Materials Ratio

c/cm

c= cement

cm= cementitious material

Equation 14: Water-Cementitious Materials Ratio

w/cm

w= water

cm= cementitious material

Equation 15: Aggregate - Concrete Ratio (Volumetric)

Aggregate Ratio (%) $= V_{aggregate}/27 * 100\%$

$V_{aggregate}$= Volume of aggregate

Aggregate Ratio (%) $= V_{aggregate}/27 * 100\%$

Equation 16: Absolute Volume of Fine Aggregate [5]

$$Abv_{Fine} = (1.0 - (sg_{cementitous} * 62.4 * 27)\text{-} (sg_{water} * 62.4 * 27)\text{-} (sg_{coarse\ agg.} * 62.4 * 27)\text{-} (Air\ Content\ from\ table)) * (sg_{fine\ agg.} * 62.4 * 27)$$

$sg_{\text{cementitious}}$ = specific gravity of cementitious material

$sg_{coarse\ agg.}$= specific gravity of coarse aggregate

sg_{water}= specific gravity of water

$sg_{fine\ agg.}$= specific gravity of fine aggregate

$$307.3 = (1.0 - (2.54 * 62.4 * 27)\text{-} (1.0 * 62.4 * 27)\text{-} (0.41 * 62.4 * 27)\text{-} (2.5)) * (2.8 * 62.4 * 27)$$

Equation 17: Coarse Aggregate Bulk Volume [5]

$$CA_{OD} = W_{od} * 27 * factor\ from\ table$$

W_{od}= Oven Dry weight ($^{lb}/_{ft^3}$)

$$15 * 27 * .55 = 222.75\ lbs$$

Appendix C – Structural & Freeboard Calculations

Equation 18: Punching Shear Demand Equation

$$\tau = \frac{P}{A}$$

Where,

τ = Shear Demand

P = Force

A = Area

Equation 19: Punching Shear Capacity Equation

$$\left(2 + \frac{\alpha_s d}{b_0}\right) \lambda \sqrt{f_c'}$$

Where,

α_s= Constant for Slabs and Footings

$d =$ Distance from Canoe Thickness to reinforcement

b_0 = Perimeter of Failure Column

λ = Modification Factor

f_c' = Compressive State of Concrete

Equation 20: Flexural Moment Equation

$$\phi Mn = \frac{\phi \cdot T \left(d - \frac{\beta_1 \cdot c}{2}\right)}{12}$$

Where,

ϕMn = Ultimate Bending Moment

ϕ = Strength Reduction Factor

T = Tension Force

β_1 = Factor of Compressive Block

c = Distance from Compression Fiber to

Neutral Axis.

Equation 21: Volume Displacement Equation

$$V_d = \frac{\Sigma f_y}{\gamma_w}$$

Where,

V_d = Volume Displacement

Σf_y = Forces Acting on Canoe

γ_w = Unit Weight of Water

Equation 22: Draught Equation

$$Draught = H - \frac{V_d}{L \cdot W}$$

Where,

V_d = Volume Displacement

H = Height of Canoe

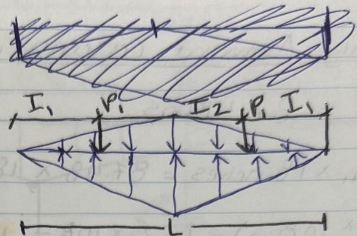
L = Length

W = Width

Equation 23: Freeboard Equation

$$Freeboard = H - Draught$$

Canoe Dimensions
L = 216 inches
I_1 = 54 inches
I_2 = 108 inches
Paddler load = 175 lbs
D = 196 lbs



Buoyancy Reaction $R = \Sigma(\text{Dead} + \text{Live}) = D + 2P$
$196 + 350 = 546\text{ lbs}$
$R_{net} = 350\text{ lbs}$

Slope of loading,
where, $h = \text{rise}/\text{run}$ $\quad h = 175/108$
$\text{Rise} = R_{net}/2 = 350/2 = 175$
$\text{Run} = L/2 = 216/2 = 108$ $\quad$ $h = 1.62\ \text{lbs/in}$

Shear Diagram Calculations:
$V_0 = 0\text{ lbs}$
$V_1 = h * x' = 1.62 \times 54 = 87.48\text{ lbs}$

$V_1' = V_1 - P = 87.48 - 175\text{ lbs} = -87.52\text{ lbs}$

$V_2 = 0\text{ lbs}$

$V_3 = -V_1' = 87.57\text{ lbs}$; $V_3' = -V_1 = -87.48\text{ lbs}$

$V_4 = 0\text{ lbs}$

Bending Moment Calculations:

$V_1 = q_1 = 87.48\text{lbs}$

$\Sigma M_1 = q_1 \times 18\text{inches} = 87.48 \times 18 = 1{,}574.64 \text{ in-lbs}$

$q_2 = (h^{*}\ 108\text{in}) = 1.62 \times 108 = 174.96\text{lbs}$

$M_2 = (q_2 \times 36) - (P \times 54) + M_1$

$M_2 = (174.96 \times 36) - (175 \times 54) + 1{,}574.64 \text{ in-lbs}$

$M_2 = -1{,}576.8 \text{ in-lbs}$

By symmetry

$M_3 = M_1 = 1{,}574.64 \text{ in-lbs}$

By symmetry

$M_4 = M_0 = 0 \text{ in-lbs}$

$\bar{Y}$ = Location of Nuetral Axis

$= \Sigma(A\bar{y}) / \Sigma(A)$

$A\bar{y} = 70.82 \text{ in}^3$
$A = 13.33 \text{ in}^2$

$\bar{Y} = \dfrac{70.82 \text{ in}^3}{13.33 \text{ in}^2} = \underline{5.31 \text{ in}}$

$I_x = 2 \times \Sigma(I_x \text{ half})$
$= 2 \times 681.86 \text{ in}^4$
$I_x = 1363.72 \text{ in}^4$ for whole canoe!

H= 16 inches

C_c = Extreme Compressive fiber

$C_c = N.A - \bar{Y} = -5.31 \text{ in}$

$C_t = \text{Height} - \bar{Y} = 16 \text{ in} - 5.31 \text{ in}$

$C_t = 10.69 \text{ in}$

Max Compressive Stress

$\sigma_c = (3.5 \times 1576.8 \times -5.31) / 1363.72$

$\sigma_c = -21.5 \text{ psi}$

$\sigma_t = (3.5 \times 1576.8 \times 10.69) / 1363.72$

$\sigma_t = 43.24 \text{ psi}$

$\tau = \frac{P}{A}$ $P = 87.57 \text{ lbs } (V_t)$
$A = 9 \text{ in}^2$ (3in×3in for Paddlers Knee)

$\tau = \frac{87.57}{9}$ $\tau = 9.73$ psi → Demand

V_c per ACI Table 22.6.5.2
ACI 318
$\lambda = 0.75$ [19.2.4.2]

$\alpha_s = 40$ (Int Column) [ACI 318 22.6.5.3]
$C = 3$ in for a column leg
$\beta = c/c = 1$ [ACI 318 22.6.5.2]
$t = 1/2$ inches * Thickness of Canoe
$t_r = 0.25$ inches * ~~thickness~~ Outside - reinforcement
$d = t - t_r = 0.25$ inches

$b_0 = 4 \times (c+d) = 4 \times (3'' + 0.25'') = 13 \text{ in}$

$f'_c = 1000$ psi

[ACI 318 22.6.5.2] *less of 3 equations from the ACI book

C.) $\left(2 + \frac{\alpha_s d}{b_0}\right) \lambda \sqrt{f'_c}$

$V_c = 65.68$ psi

9.73 psi < 65.68 psi ✓

* Demand is lower than Capacity

Modulus Of Rupture = $f_r = 7.5\lambda\sqrt{f'c}$

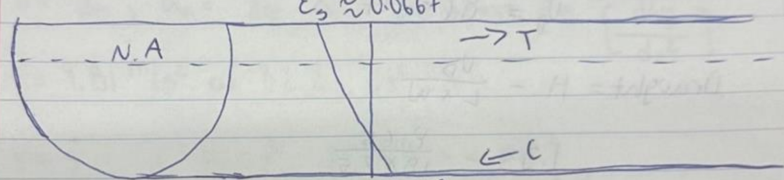
$$f_r = 7.5(0.75)(\sqrt{1000}) = 177.88 \text{ psi}$$

Cracking Moment

$$M_{cr} = \frac{f_r \cdot I_g}{y_t} = \frac{177.88 \times 1363.72}{5.31}$$

$$M_{cr} = 45{,}683.34 \text{ lb-in} = \underline{3{,}806.94 \text{ lb-ft}}$$

T = 6.6 Kips = 6600 lbs



T = 6,600 lbs from reinforcement $\phi = 0.90$, $\beta_1 = 0.85$

$$C = \frac{6{,}600}{0.85 \cdot 1000 \cdot 0.85 \times 1} \qquad C = 9.13 \text{ in}$$

$$M_n = T\left(d - \frac{\beta_1 \cdot c}{2}\right)$$
$$= 6{,}600\left(16 - \left(\frac{0.85 \cdot 9.13}{2}\right)\right)$$

$$M_n = 79{,}990.35 \text{ lb-in} = 6665.86 \text{ lbs-ft}$$

$$\phi M_n = (0.90)(6{,}665.86) = \underline{5{,}999.28 \text{ lb-ft}}$$

Max Moment = 1576.8 in-ft < 5,999.28 lb-ft
131.4 ft-lb ✓

$$\text{Volumne Displacement} = \frac{\Sigma fy\ lb}{\gamma_w}$$

$$\frac{(175 + 175 + 190)}{62.4}$$

$$V_D = 8.65\ ft^3$$

$$\text{Draught} = H - \frac{V_D}{L \times W}$$

$$1.33 - \frac{8.65}{18 \times 2.5}$$

$$\text{Draught} = \underline{1.14\ ft}$$

$$\text{Freeboard} = H - \text{Draught} = 1.33 - 1.14$$

$$\text{Freeboard} = \underline{0.193\ ft}$$

Appendix D - Hull Thickness/Reinforcement and Percent Open Area Calculations

Hull Thickness

Equation 24: Composite Thickness Ratio

$$CRT = \frac{Total\ einforcement\ Thickness}{Total\ Concrete\ Thicknes}$$

$$CRT = \frac{.04}{.50} = 0.04$$

Composite Ratio = 40% < 50%, Compliant

Percent Open Area

Table 9: Primary Reinforcement Sample Dimensions

Dimensions	Value	Units
d1	0.625	in
d2	0.6875	in
t1	0.1875	in
t2	0.125	in
n1	7	--
n2	5	--
Sample Length	4.18	in
Sample Width	5.9	in

Equation 25: Area of Apertures

$$A_{ap} = d_1 * d_2$$

Where,

A_{ap} = Area of Single Aperture, in^2

d_1 = Reinforcement Opening Width, in

d_2 = Reinforcement Opening Width, in

Equation 26: Open Reinforcement Area

$$\sum Area_{open} = n_1 * n_2 * A_{ap}$$

Where,

n_1 = Number of Apertures along height

n_2 = Number of Apertures along height

A_{ap} = Area of Single Aperture, in^2

Equation 27: Total Area of Reinforcement

$$Area_{total} = Sample\ Length * Sample\ Width$$

Equation 28: Percent Open Area

$$POA = \frac{\sum Area_{open}}{Area_{total}}$$

Table 10: Results of POA Analysis

Dimension	Value	Units
Open Area	15.05	in^2
Total Area	24.3	in^2
POA > 40%	61.9	%

Equation 29: Bulkhead Length

$$L_B = \frac{\frac{V_c * \gamma_c * 2}{\gamma_w} - V_c}{2A_b}$$

Where,

L_B = Length of Bulkhead (ft)

V_c = Canoe Volume (cf)

γ_c = Required Density (pcf)

γ_w = Density of Water (pcf)

A_b = Average Cross-Sectional Area of Bulkhead (cf)

Appendix E – Supporting Documentation

We acknowledge that we have read the 2024 ASCE Society-wide Concrete Canoe Competition Request for Proposal and understand the following (*initialed by one (1) team captain and ASCE Faculty Advisor*):

Statement	**Captain Initials**	**Advisor Initials**
The requirements of all teams to qualify as a participant in the ASCE Student Symposium and Society-wide Competitions as outlined in Section 3.0 and Exhibit 3.	D.M.C	ML
The eligibility requirements of registered participants (Section 3.0 and Exhibit 3).	D.M.C	ML
The deadline for the submission of *Letter of Intent, Preliminary Project Delivery Schedule* and *Pre-Qualification Form* (uploaded to ASCE server) is November 3, 2023; 5:00 p.m. Eastern.	D.M.C	ML
The last day to submit *ASCE Student Chapter Annual Reports* to be eligible for qualifying (so that they may be graded) is February 1, 2024.	D.M.C	ML
The last day to submit a *Request for Information* (RFI) to the C4 is January 29, 2024.	D.M.C	ML
Teams are responsible for all information provided in this *Request for Proposal*, any subsequent RFP addendums, and general questions and answers posted to the ASCE Concrete Canoe Facebook Page, from the date of the release of the information.	D.M.C	ML
The submission date of the *Project Proposal*, *Mix Design Sheets*, and *Materials Notebook* for the Student Symposium Competition (uploading of electronic copies to ASCE server) is Friday, February 16, 2024.	D.M.C	ML
The submission date of the *Project Proposal*, *Mix Design Sheets*, and *Materials Notebook* for Society-wide Final Competition (hard copies received by ASCE and uploading of electronic copies to ASCE server) is May 15, 2024; 5:00 p.m. Eastern.	D.M.C	ML

Dylan M Condra 11/01/2023
Team Captain *(date)*

Mark Lamer 11/03/2023
ASCE Student Chapter Faculty Advisor *(date)*

(signature)

MarkLamer

(signature)

Northern Arizona University

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Phone:(480)684-4719

Mark Lamer
Email: Mark.Lamer@nau.edu
Phone:

Figure 11: Pre-Qualification Form Page 1

In 250 words or less, provide a high-level overview of the team's Health & Safety (H&S) Program. If there is currently not one in place, what does the team envision their H&S program will entail?

The team's Health and Safety program includes an extensive safety binder which consists of a detailed project background, which covers the project's objectives, tasks, and testing. Prior to stepping foot in the lab or construction location, the individual must thoroughly read the contents of the safety binder. The Binder explains the numerous types of hazards and lists materials and chemicals used which could cause harm to oneself or the equipment being used. The binder describes the general safety procedures, protective gear, appropriate clothing, and the power and hand tools which will be used. Virtual training videos explaining the proper use of tools, proper procedures of testing, and when to use protective gear is provided. An activity log will be recorded describing the task completed and the people present. Any incident where an individual or tool has been damaged an incident report will be filed.

In 150 words or less, provide a high-level overview of the team's current QA/QC Program. If there is currently not one in place, what does the team envision their QA/QC program will entail?

The team's Quality Assurance and Quality Control program involves a detailed schedule including every task in order of completion to ensure the timely delivery of all Documents and Models prior to their respective deadlines. The team will seek guidance from technical advisors to ensure an accurate and high-quality document. Every decision made will be supported by manual and automated testing to construct a high-quality model in every regard with regular checks if the designs meet the ASCE rules and regulations. The construction of the model will be handled meticulously with prior practice attempts to limit human error. The model will cure in a curing chamber until the maximum strength is achieved. Additionally, regular inspections will be conducted at all times of construction to address any defects which will be handled promptly. Proper storage and transportation methods will be implemented when required to ensure no damage comes to the model.

Has the team reviewed the Department and/or University safety policies regarding material research, material lab testing, construction, or other applicable areas for the project?

Yes, the team is currently in the process of completing the department's safety policies, moving forward into using lab areas and construction.

In 150 words or less, provide your team's perspective on the use of ChatGPT and other AI/NLP algorithms in the competition. Do you intend to use it? If so, in what areas? (Note: C4 neither

Figure 12: Pre-Qualification Form Page 2

encourages or discourages the use of AI/NLP algorithms, but is interested in collecting data on student usage in the competition.)

Our team's perspective on ChatGPT and other AI-affiliated services is to only be used as an idea generator rather than a solution to our problems. Being able to point us in the right direction after seeking guidance from our professors, technical advisors, and other professionals. The use of AI-affiliated services is considered plagiarism by the team and strictly prohibited in any document.

The core project team is made up of _5_ number of people.

Figure 13: Pre-Qualification Form Page 3

Appendix F – Detailed Fee Estimate

Table 11: Detailed Fee Estimate

Engineering Services Cost Estimate (Per 100 Canoes)				
Description	**Quantity**	**Units**	**Rate (USD)**	**Cost**
Personnel				
PDE	Task Nam	Hr.	$120	$17,880
PM	PDE Hours	Hr.	$88	$13,464
TD	PMHours	Hr.	$62	$8,742
EIT	TDHours	Hr.	$87	$12,006
QM	EIT Hours	Hr.	$38	$7,942
Total Personnel				**$60,034**
Travel for Competition				
Transportation	1,206	Miles	$0.40	$482
Van Rental	1	Van/Week	$340	$340
Hotel Rooms (2 rooms)	3	Nights	$400	$1,200
Meals (5 People, 4 Days)	3	Meals/Day/ Person	$20.00	$1,200
Total Travel				**$3,222**
Lab Use				
Farm	10	Days	$200	$2,000
Geotech Lab	10	Days	$200	$2,000
Water/Concrete Lab	10	Days	$200	$2,000
Total Lab Use				**$6,000**
Subcontract				
Mold Manufactour	5	Days	$200	$1,000
Western Tech	5	Days	$200	$1,000
Total Subcontract				**$2,000**
Matertials				
Cementious Materials	10	Cubic Feet	$8	$80
Aggregate	12	Cubic Feet	$75	$900
Sand	5	Cubic Feet	$10/ton	$1
Admixtures	1	GAL	$20	$20
Reinforcement	20	Square Yard	$15	$300
Total Materials				**$1,301**
Project Total				**$72,558**

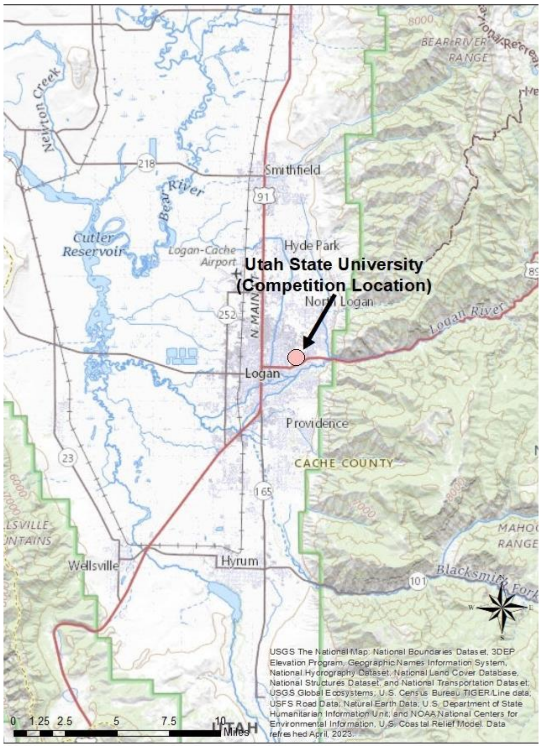
7.0 Introduction

Our team's project is the 2024 Concrete Canoe Competition. The objective of this project is to design a canoe, create three concrete mix designs, material testing, structural analysis of the canoe, an in-depth cost estimate of creating 100 canoes, create a display, compete in 3 different races, and lastly present in front of a panel of judges. The project location will take place at Utah State University's Logan, UT, as seen in Figure 14 The campus will be hosting the C4 Intermountain Southwest Conference (ISWS) competition in mid-April 2024. The team will be competing against neighboring colleges Utah State, Arizona State, and the University of Arizona. Our client for this project is Mark Lamer. Background information for this project is described above in Section 1. The design of the concrete mixture and canoe hull are described above in 4.1 through 4.2 and 4.3, respectively. The construction and fabrication of the canoe is described above in sections 4.4 and 4.7, respectively.

Commented [RT10]: "The objective of this project is …"

Commented [RT11]: Background information for this project is described above in Section xx … the design of the concrete mixture and canoe hull are described above in xx and xx, respectively. The construction and fabrication of the canoe is described above in section xx and xx, respectively.

Figure 14: Project Location



8.0 Engineering Work Done

8.1 Proposed Work Hours

A detailed summary of the proposed work hours compared to the actual work hours is seen below in Table 12: Proposed vs Actual Work hours .This table shows the hours each team member put in for the task at hand. The actual hours are 42% more than the proposed hours, which is a result of losing a team member which increased workloads for all other members and delayed the project deadlines.

Table 12: Proposed vs Actual Work hours

Task Name	PDE Hours	Actual Hours	PM Hours	Actual Hours	TD Hours	Actual Hours	EIT Hours	Actual Hours
Task 1: Background Research	20	48	58	45	49	55	24	60
Task 2: Concrete Mixture Design	10	8	48	82	34	2	17	7
Task 3: Hull Design	26	0	7	0	17	48	9	47
Task 4: Decision Matrix	13	6	9	6	11	6	11	6
Task 5: Analysis of Decision Matrix	4	5	9	2	15	20	22	25
Task 6: Canoe Fabrication	20	55	16	44	16	75	28	65
Task 7: Pre-Competition Prep.	8	19	4	17	4	20	4	19
Task 8: Deliverables	40	59	40	61	40	50	40	55
Task 9: Project Impact Analysis	6	2	6	2	6	1	6	1
Task 10: Project Management	40	45	30	35	20	25	20	25
Subtotal:	187	247	227	294	212	302	181	310
Total Proposed:		807	**Actual Total:**					1,153

9.0 Competition

9.1 Pre-Competition

Pre-competition preparation began with touching up the final parts of the canoe. The team sanded the exposed interior of the canoe, patching all concerning cracks, or holes. Figure 16 shows the patchwork done on the bulkheads which showed notable cracks.

Figure 15: Patch Work

Following the removal of the mold, the same process of sanding and patchwork was used on the exterior. The patchwork sections were cured for 3 days before the sealant could be applied. 2 coats of silicone-based sealant were applied to the entire canoe. Each layer was allowed 1 hour to cure before another layer was applied in figure 17 seen below shows the sealant process.

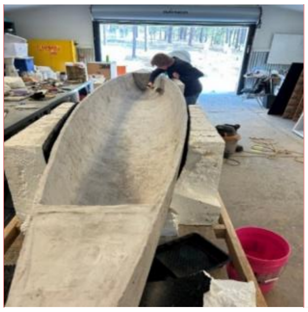


Figure 16: Applying Sealant

After the final touches of the canoe were completed and the sealant had completely dry. The team reused the metal-framed canoe cart seen below in Figure 18. Upon loading the trailer for the ISWS conference the canoe was loaded with all required personal protective equipment, display objects, and decorative items as seen in Figure 19 below were loaded into the trailer and secured tightly.

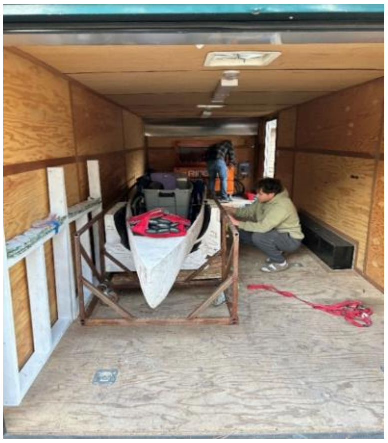


Figure 17: Loading Canoe

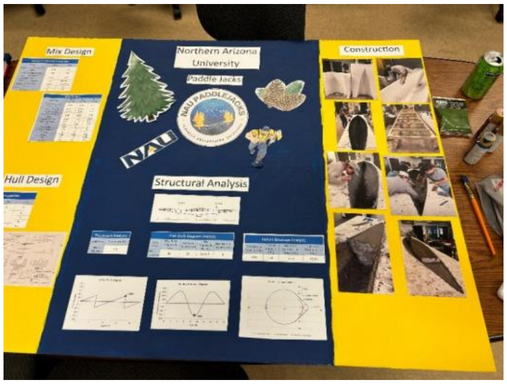


Figure 18: Project Display

Commented [RT12]: Format paragraph keep with next so that it doesn't wrap to next column

9.2 Competition Results

In Table 13: Competition Results, the results will be displayed for each of the competitions that the team participated in. Due to the delay from Utah State University (USU), the results are not yet known.

Table 13: Competition Results

Ranking	Results
Report	To be determined
Display	To be determined
Presentation	To be determined
Race	To be determined
Overall	To be determined

10.0 Cost

An in-depth summary of the proposed and actual costs including engineering services, travel, material, and subcontracting costs is seen below in Table 15. The in-depth proposed cost estimate can be found in Table 13 seen above. The actual cost is 62% greater than the proposed cost. This large difference is a result of one member being removed from the project which put more workload on the other members. The member who was removed was the QM role which was $38 an hour. His anticipated workload and hours were then divided up between other high-paid employees ranging $62-$120 an hour who had to make up the difference. This caused delayed due dates and required more work from higher-paid employees.

Commented [RT13]: That doesn't make sense. If you lose an employee and remaining employees have to do the same amount of lost work then the cost should be a wash unless you lost a low paid employee and had to make the difference up with higher paid employee

Table 14: Proposed vs Actual Cost

Engineering Services Cost Estimate (Per 100 Canoes)					
Description	**Quantity**	**Units**	**Rate (USD)**	**Actual Costs**	**Proposed Costs**
Personnel					
PDE	247	Hr.	$120	$29,640	$17,880
PM	294	Hr.	$88	$25,872	$13,464
TD	302	Hr.	$62	$18,724	$8,742
EIT	310	Hr.	$87	$26,970	$12,006
QM	0	Hr.	$38	0	$7,942
Total Personnel				**$101,206**	**$60,034**
Travel for Competition					
Transportation	1,206	Miles	$0.40	$482	$482
Van Rental	1	Van/Week	$340	$340	$340
Hotel Rooms (2 rooms)	5	Nights	$400	$2,000	$1,200
Meals (4 People, 4 Days)	4	Meals/Day/ Person	$20.00	$960	$1,200
Total Travel				**$3,782**	**$3,222**
Lab Use					
Farm	26	Days	$200	$5,200	$2,000
Geotech Lab	14	Days	$200	$2,800	$2,000
Water/Concrete Lab	16	Days	$200	$3,200	$2,000
Total Lab Use				**$11,200**	**$6,000**
Subcontract					
Mold Manufacturer	8	Days	$200	$1,800	$1,000
Western Tech	2	Days	$200	$400	$1,000
Total Subcontract				**$2,200**	**$2,000**
Materials					
Cementitious Materials	4.1	Cubic Feet	$8	$33	$80
Aggregate	8.6	Cubic Feet	$75	$645	$900
Sand	5	Cubic Feet	$10/ton	$1	$1
Sealant	5	GAL	$34	$170	$20
Reinforcement	20	Square Yard	$15	$300	$300
Total Materials				**$1,149**	**$1,301**
Project Total				**$119,537**	**$72,558**

11.0 Project Impacts

Table 15: Canoe Capstone Impacts, seen below explains the positive and negative impacts for social, Environmental, and Economical. Table 17 compares these impacts with last year's concrete canoe team and the current teams impacts for their respective canoes.

Comparing last year's teams canoe to this year's there was more mentee involvement last year which will lead to more interest into the capstone and civil engineering by getting more people involved. One aspect that does come from the capstone is the competition and how well that the team does during it. Participating in the competition reflects on the college and the future capstone going forward, because last year's team wasn't able to complete the swamp test it put more pressure on the future year to create a more buoyant canoe.

With environmental impacts this year was able to replace 75% of the cement used in the mix design compared to last year's 70%. Both reduce the amount of CO2 created from the concrete industry so being able to reduce the cement used in the design helps reduce greenhouse gasses. Reducing cement is one way, but also using alternative materials to create the concrete. Last year used slag, fly ash, and PC4 while this year used the same materials and aero aggregate for more waste materials to be used in the canoe. Both teams did have to order materials from outside the state which means more CO2 was created than if the materials were sourced locally. Last year's team had materials like slag, fly ash, and expanded shale come from Utah, while our aero came from Florida. The aero is a recycled material but has to come from across the country in order for us to use it. Another impact this year had was using existing materials from the farm, so materials won't pile up over time from purchasing new materials.

From economic impacts, last year's team was able to highlight the use of PC4 for their canoe which brings attention to more use of alternative materials and resources for concrete use. Comparing last year's budget with this year, last year was team went over budget and had to start playing out of pocket to complete the capstone. This year's team was able to stay under the budget and still complete the project.

Table 16: Triple Bottom Line goes over how the team scored each impact from the respective year. After summing up each category the current year had a sustainability index of 145, while last year had a value of 130.

Table 15: Canoe Capstone Impacts

	Last Years		Current Years	
Impacts	**Positive**	**Negative**	**Positive**	**Negative**
Social	• More mentee involvement	• Didn't pass swamp test	• Passed swamp test	• Less mentee involvement
Environmental	• Started use of PC4 • Replaced 70% of cement in mix	• Out-of-state products from Utah	• Used existing materials from the farm • Replace 75% of cement	• Aero Aggregate came from Florida
Economical	• Able to highlight PC4 as an alternative material	• Over budget • High-cost production • Heavy Canoe	• Under budget • Sourced product locally as much • Expanded on existing sponsors • Light Canoe	• Interacting with vendors • High cost of production

Table 16: Triple Bottom Line

	Social	Economical	Environmental	Total	Min-Max	SI
Last Years	60	40	50	150	20	130
Current Years	55	45	60	160	15	145

Commented [RT14]: Can you put this in terms of big picture. The benefit to society by involving mentees is huge but a canoe that doesn't float impacts the image of NAU ASCE chapter. I'd say those are about a wash. I agree with your scoring but don't want you to focus on small details

Whether it is lighter or heavier would effect the ECONOMIC potential of the prototype

Commented [RT15]: How much cement did you replace? That has a big effect on carbon footprint and environmental impact. How much waste materials last year vs. this year? How did your shipping compare with their shipping. If you can quantify all of these you can make an objective comparison

Commented [RT16]: Weight should go here - in terms of the potential for canoe to be mass produced and inevitably shipped.

How does your production cost compare with last years?

How are these canoes disposed/re-purposed? It would be nice to find a way

12.0 Conclusion

Based on the goals of creating a workable, functioning prototype, the team was successful. By following the design criteria outlined in the Concrete Canoe Competition Committee (C4) rules, the design provided the opportunity to engage in new technical skills. In addition, assistance from mentees and tips from previous teams contributed to the prototype's prosperity. The capstone competition improved new skills such as project management, resource management, concrete mix design, structural analysis, hull design of the canoe, and general skills to effectively work in a team. Other focuses included creating a proposed budget, schedule, people hours on the project, and the impact of the project on a societal, environmental, and economic level. To meet the requirements of the client, the report provides a breakdown of all the calculations and data to exhibit the production methods and what the client can expect in terms of quality and finished product.