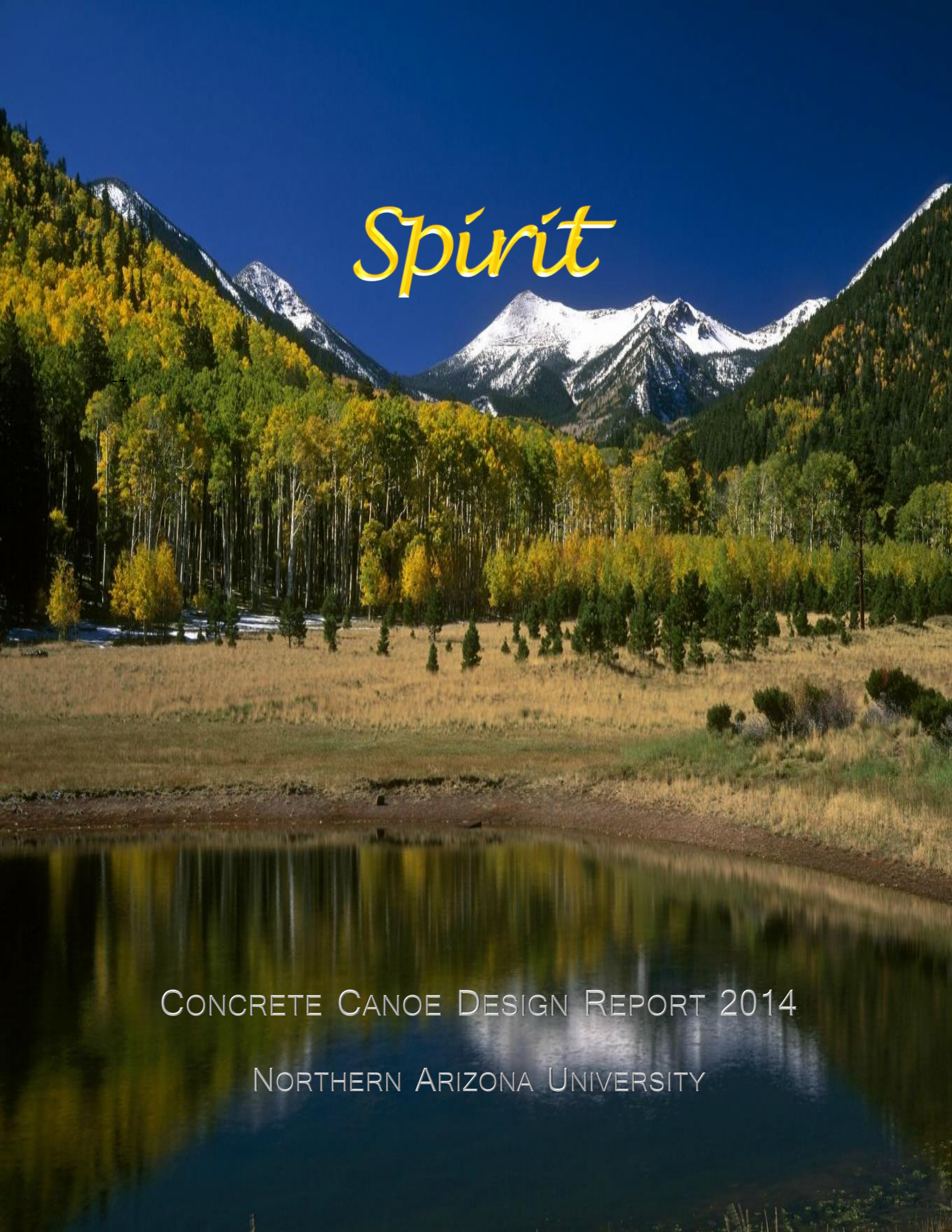

Spirit

Concrete Canoe Design Report 2014

Northern Arizona University

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Executive Summary

Spirit is one of the major components that we wanted to improve upon at our university, as well as within ourselves. Spirit is the essence of courage, energy, and determination. The design and construction of *Spirit* encompassed all three traits and truly became more than just a project, but something that taught the team the true meaning of spirit and pride.

NAU is located over 7,000 feet above sea level in the mountainous terrain encompassing Mount Elden and the San Francisco Peaks in Flagstaff, Arizona. Since its founding in 1899 with 23 students and 1 instructor, NAU has expanded to comprise 6 colleges, including the College of Engineering, Forestry, and Natural Sciences. There are approximately 25,000 students currently enrolled, with 490 undergraduates in the Civil and Environmental Engineering Department.

After the establishment of the first NAU concrete canoe team in 1977, they qualified for the National Concrete Canoe Competition (NCCC) from 1989 to 1993. Though they had a great run of success and national appearances, NAU has failed to advance to nationals since. In 2011, *Ponderosa* took 7th overall at the Pacific Southwest Conference (PSWC) and in 2012, *Betula* was placed even lower. However, in 2013 *Night Fury* placed in the top six in the overall team scoring bracket at PSWC. NAU is one of 18 schools that compete at the regional PSWC alongside universities from Southern Nevada, Arizona, Hawaii, and Southern California.

The hull design used for *Spirit* was also utilized by last year's team, *Night Fury*. This particular hull shape features a medium rocker v-shape that increased the speed and maneuverability in comparison to the standard hull shape provided by the CNCCC. Additional information on the canoe's specifications can be found in Table 1.

Table 1: *Spirit* Specifications

Canoe Name	***Spirit***
Estimated Weight	206.7 lbs
Length	228 in
Maximum Width	27 in
Maximum Depth	14.3 in
Average Thickness	0.5 in
Concrete Color	Medium Grey
Stain Colors	Blue, Gold, Green
Reinforcement	Stucco Fiberglass Mesh

Since *Spirit's* hull design matches *Night Fury*, we were able to use *Night Fury's* calculations as a baseline. The overall goal for *Spirit* was to increase the workability and compressive strength of the concrete mixes to eliminate the use of post tensioning (PT) strands. The concrete designed for *Spirit* is the first of its kind to include fine fibers to reduce cracking. Three load combinations were investigated. Design of the reinforcement was also completed using a linear analysis of the tensile strain. Table 2 contains the final concrete mix design properties.

Table 2: Concrete Properties

Wet (Plastic) Unit Weight	98.1 lb/ft^3
Dry Unit Weight	81.1 lb/ft^3
Compressive Strength	4,536.0 psi

Spirit entails the ambition of the team to overcome all odds. *Spirit* encompasses the team's dynamic personality, determination, energy, and courage to break down from traditions and explore new ways that will set us apart from the rest. *Spirit* is another stepping stone for future canoe teams that will bring NAU back into rightful place at conference.

Project Management

This year's concrete canoe team is comprised of four members, which made management a critical task. In order to complete this design in an effective and timely manner, the project was broken into three categories; reinforcement design, concrete development, and structural analysis. Each category had a lead designer.

Active involvement from each captain in other aspects of the canoe proved to be more vital than expected. Having multiple individuals engaged in the different design processes worked in the team's favor to complete a noteworthy final product.

In late September, the team drafted a project schedule consisting of all major milestone activities. Based on previous NAU concrete canoe schedules, the team identified four critical path activities that were determined based on the most impact on completing the project on time. These tasks were fundraising and acquiring a facility, mix design and testing, structural and reinforcement analyses and design, and canoe construction. Project milestones can be seen in Table 3.

Table 3: Project Milestones

Milestone	Variance	Reason
Final Mix Design	+18 days	Fine Tuning The Final Mix
Pour Day	+32 days	Additional Development
Final Report	+3	Additional Corrections
Conference Attendance	None	N/A

To ensure that the team stayed on task, meetings were scheduled accordingly. Certain tasks within the schedule were over estimated to account for any unforeseen circumstances that might hinder the task from being completed.

Figure 1 gives the percentage estimate for each category involved with the creation of *Spirit*. The estimated amount of man-hours needed to complete *Spirit* is 1,680.

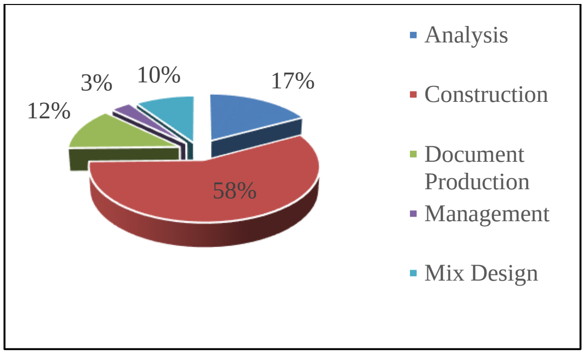

Figure 1: Estimated Man-hour Distribution

Spirit had an estimated budget for design and construction of $3,000. Through extensive fundraising efforts, *Spirit* received a generous monetary donation of $2,000 as well as $1,000 from the civil engineering department. The conference segment presented in Figure 2 is not included within the team's budget. These expenses will be solely covered by the civil engineering department.

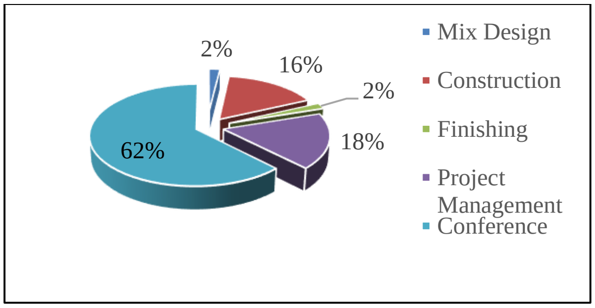

Figure 2: Allocation of Expenses

One of the structural analysis leads served as the primary quality control, quality assurance, and safety officer. Before any materials were handled, MSDS sheets were reviewed. The safety program required everyone to wear long pants, long sleeves, and closed toe shoes during construction or testing of the materials. Furthermore, dust masks and goggles were required while mixing concrete batches. Gloves and safety glasses were required during casting. All volunteers were required to sign a safety plan written by the project manager.

Organization Chart

Project Management & Reinforcement Design

Hannah Williams

- Oversee schedule, finances, quality control/safety, task delegation, material procurement, and document production
- Research reinforcement and develop reinforcement scheme
- Developed safety plan
- Assisted with concrete mix designs

Concrete Design

Brent Allman

- Research materials and develop mix designs
- Test concrete mixes and reinforcement
- Document production
- Quality Control
- Assisted with reinforcement analysis

Structural Analysis

Ariel Suarez

- Performed hand calculations and computer software analysis
- Document production
- Schedule development
- Quality control and safety

Shuo Zhang

- Performed hand calculations and computer software analysis
- Document production
- Assisted with concrete mix designs

Mold Fabrication
Night Fury Team

Canoe Fabrication
All Captains
~ 15 volunteers

Presentation
Hannah Williams
Shuo Zhang

Paddlers
Brent Allman
Todd Brewer
Noël Cruz
Jeremy DeGeyter
Brent Lipar
Alejandra Quesada
Ariel Suarez
Kristin Van Sciver
Hannah Williams
Shuo Zhang

Display
Ramon Aguilar
Cynthia Alvarez
Jeremey DeGeyter

Staining
Ariel Suarez
Hannah Williams

Cross Section
Brent Allman
Shuo Zhang

Advisors
Mark Lamer
Thomas Nelson
Dr. Robin Tuchscherer

Hull Design and Structural Analysis

After last year's success with *Night Fury*, the general hull design was incorporated into *Spirit*. The hull design goals set out by team *Night Fury* included four design criteria: tracking, ease of construction, speed, and maneuverability. These goals helped *Night Fury* to produce an asymmetrical canoe with a moderate rocker shape that allowed for easy tracking as well as maneuverability. The hull design includes a wetted surface area of 33.6 square feet, a beam width of 27.4 inches, max drag coefficient of 11, and a displacement to length ratio of 53.8. The team completed a cost-benefit analysis that reinforced the decision to reuse *Night Fury's* mold and found that to build an entirely new mold would cost almost $1,000 dollars in materials.

Using the same hull, the waterlines were recalculated along the entire length of the canoe in increments of 14 inches. The team began by establishing waterlines at 8, 10, and 12 inches. The areas for each of the sections that were below the waterline were summed, averaged and multiplied by the density of water to find the total buoyant force. These values were compared to the total force on the canoe under different load cases. The four person condition produced a total load of 897 pounds which includes an overestimated self-weight of 300 pounds. Through basic interpolation between the waterlines of 8, 10, and 12 inches, the waterline for each of the load scenarios was calculated until the buoyant forces equaled the applied load. The waterline for the four person condition equated to 11.09 inches, giving a minimum freeboard of 3.21 inches. The waterline for the 2 female and 2 male were determined to be 8.60 and 9.11 inches, respectively.

The forces and stresses within the canoe imposed by both the water and the different load scenarios were analyzed to determine where the highest stresses occur within the canoe. Using RISA 2D, a simple beam was analyzed for each of the load scenarios with primary focus on the four person load. Four different conservative loads were applied to the beam located at the lengths approximated in the waterlines to ensure equilibrium. Point loads of 127, 160, 170, and 140 pounds were placed approximately 78, 126, 147, and 175 inches from the bow along the beam. Figure 3 illustrates the locations of the point loads along with the distributed load from the buoyant forces and self-weight of the canoe.

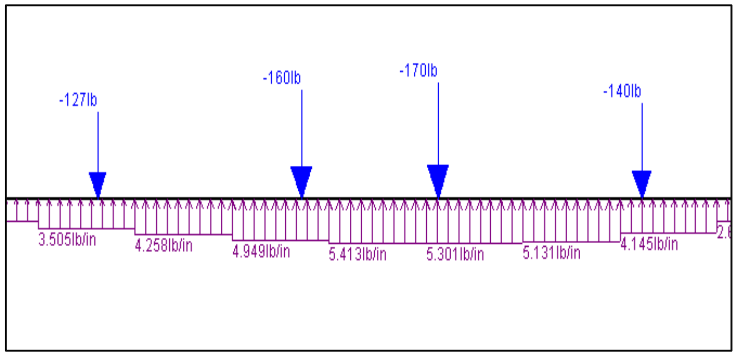

Figure 3: Load Locations and Distributed Loads (Note: full length of the canoe is not depicted in the figure.)

From the waterline calculations, the distributed load imposed by the change in buoyant force was divided into 14 inch increments along the length of the canoe. The resulting distributed loads were applied to the bottom of the beam. For the next step, the self-weight of the canoe was divided into appropriate increments to represent the distribution of the weight. To accomplish this part of the calculations, the volume of the canoe was found by multiplying the volume for each section by the density of concrete. The approximate weight of each section was then divided by its length to yield the distributed load per section. These distributed loads were applied to the canoe in 14 inch increments as described above. Based on this analysis, the maximum moment for the four person condition was determined to be 237.5 lb-ft. Three other moments were also

observed, which included 151.1, 235.2, and 140.3 lb-ft. Knowing the locations of the maximum moments was essential in the next step of the analysis which was to determine the amount of reinforcement.

To compensate for the elimination of PT strands, the final concrete mix design had a higher tensile strength and incorporated fine fibers to aid in crack control. To accomplish this goal, the team set out to make the concrete mix as strong as possible. In doing so, the density was increased yet the slump was maintained below 2 inches. The resulting compressive strength reached a maximum of 4.5 ksi. *Spirit*'s goal was to indirectly increase the tensile strength by increasing the compressive strength, maintain a workable yet playdough-like consistency of the concrete mix, and conduct an accurate primary reinforcement analysis. Since the compressive strength of the concrete was substantial, the team determined to utilize fiberglass mesh to provide tensile capacity and ribs to stiffen the hull.

After determining the locations of the max longitudinal and transverse moments, the team took cross sections at these designated rib locations. Then the rib cross sections were analyzed similar to how a reinforced concrete beam is flexurally analyzed. Figure 4 is an example of how the cross sections were analyzed.

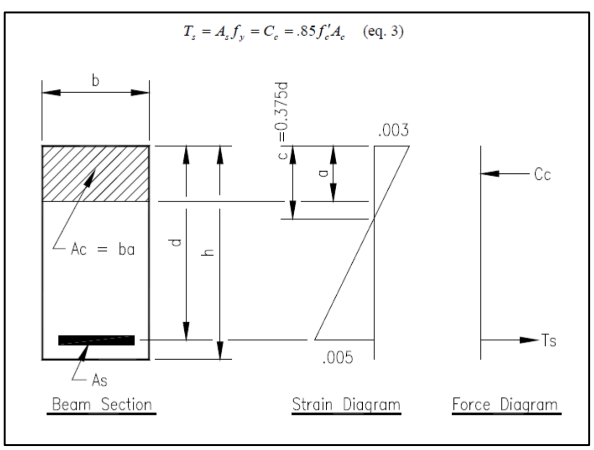

Figure 4: Example of Rib Design Analysis

To perform this calculation, the tensile strength, modulus of elasticity, and yield strain of the fiberglass mesh needed to be defined. The ultimate tensile stress per strand was tested to be 6.19 ksi. Using engineeringtoolbox.com (2014), the modulus of elasticity was assumed to be 2400 ksi. Applying Hooke's law, $\sigma = E\varepsilon$, the yield strain per strand was calculated to be 0.0026 in/in. The team was able to flexurally analyze the ribs and ensure that their capacity was greater than the maximum transverse moment demand. As a result, in the four locations with the highest transverse moments, 12 in x 2 in x 0.5 in ribs were placed to provide a higher moment capacity to resist the moment demand imposed by the water.

The dry unit weight of concrete was determined to be 81.1 pcf. Since the density of the concrete is heavier than the density of water, the team had to include foam in the hull. The team used a combination of spray foam and foam board as the buoyant material. This was crucial to ensure that the canoe would be able to pass the swamp test. The volume of the canoe was calculated using the cross section drawings created for *Night Fury*. Using the desired thickness of 0.5 inches, the overall volume of concrete was estimated to be 2.55 cubic feet. After considering the buoyancy of water, the remaining density was used to determine the buoyant weight of the canoe. The result was that the canoe weighed 206.7 pounds in water. After extensive research, a factor of safety (FS) of 1.33 was determined to be the best option (Darla). This FS was multiplied by the difference in the buoyant force and canoe weight. The volume of foam needed was determined by dividing the excess weight by the difference between the density of water and the density of foam used.

Finally, an analysis of shipping stresses was eliminated due to the fact that a "coffin" composed of 15 individual supports was utilized to transport the canoe.

Development and Testing

The goals set forth by the team for the concrete mix design this year were to have a playdough-like consistency, sufficient workability, a slump of less than one inch, a minimum compressive strength of 3,000 psi and increase the tensile strength to eliminate the use of PT strands.

Night Fury's mix design was used as a baseline since one of our overall goals this year was to improve upon their design. The mechanical properties of their mix had a compressive strength of 1,570 psi and a unit weight of 61.5 pcf. *Night Fury*'s mix design consisted of Type I white Portland cement, Class F Fly Ash, 3M™ K1 glass bubbles, 0.5-2mm Poraver© recycled glass beads, cenospheres, Glenium® 3030, and MB-AE™ 90.

The adjustments implemented to improve *Night Fury's* mix included researching and testing fine fibers, admixtures, aggregates, and modifying mix ratios. Figure 5 below depicts one of the many creations of the final mix design and as well as a sample sheet.

Figure 5: Concrete lead making cylinders and a sample sheet

The effect of admixtures from last year's mix design were compared and tested against mixes without these admixtures, and with the addition of lime. This new cementitious material was selected due its ability to reduce shrinkage, cracking, and improve workability. Although the lime reduced the compressive strength, the difference was so small that it did not warrant a disqualification of this material.

Aggregates were selected in order to increase strength and maintain proper consistency. Although this year's team was satisfied with the sustainability and performance of the Poraver© aggregate, the desired slump and compressive strength were not fulfilled. Therefore, Mortar sand was used as a secondary aggregate to adjust these mechanical properties.

Testing of the concrete mixes was in accordance with the following standard test methods; compressive strength (ASTM 39/C 39M), slump (ASTM C143 / C143M), and air content (ASTM 138/C 138 M). Other test methods utilized by the team were the restrained ring test and a sample sheet test. As the restrained ring test assesses resistance to restrained shrinkage cracking, this method was used to compare the difference between *Night Fury*'s mix design and *Spirit*'s. The sample sheet test is a 1 ft by 1 ft section in which the workability or ease of application of the mix design was tested. Figure 6 below shows the two mixes side by side during the shrinkage ring test and a freshly made sample sheet.

Figure 6: *Top:* Restrained Shrinkage Ring Test – *Night Fury* mix design (left), *Spirit* mix design (right). *Bottom:* Sample

After analyzing all 12 mix designs, mixes #5 and #11 were the only two that met the set

criteria. After further review, mix #11 provided slightly better results. Table 4 compares the results of these two mixes with the set criteria.

Table 4: Concrete Mix Designs

Characteristics	Set Criteria	Mix #5	Mix #11
Strength (psi)	> 3,000	4,436	4,536
Unit Weight (lb/ft^3)	< 2/3 normal concrete	104	81.1
Workability – "Slump" (in)	< 2"	1	1

After an extensive literature review, the reinforcement used last year, HexForce Fiberglass Mesh, was compared to white and green stucco fiberglass mesh, welded wire mesh, and geogrid. The flexibility/ workability/molding with the shape of the canoe, percent open area (POA), and quality of bond with the concrete were parameters compared on the primary reinforcement. The white and green stucco fiberglass mesh met these requirements.

As a secondary reinforcement measure, the team investigated internal fibers because the use of this reinforcement would aid in the control and distribution of cracking. To select a fiber, a test method was utilized based on ASTM C1581 / C1581M - 09a Standard Test Method for Determining Age at Cracking and Induced Tensile Stress Characteristics of Mortar and Concrete under Restrained Shrinkage. Fibers were researched and tested based upon the following factors: aesthetics, ability to control/reduce overall cracking, and bonding with concrete. The use of the restrained shrinkage ring and sample sheet tests as well as a decision matrix was utilized to determine the best fiber. The fiber that met this criteria was the Fibermesh® 150. The reasoning behind the categories analyzed for the fibers are shown in Table 5.

Table 5: Fiber Reasoning

Aesthetics	Based on how the fibers look in the concrete when placed
Ability to control/ reduce overall cracking	Based on restrained ring test which observes the sizes of cracks occurring during curing process
Bonding with concrete	Based on the fibers ability to merge with the mix design without causing lamination

The green stucco fiberglass mesh was tested in direct tension by hanging weights from two strands until failure occurred. Figure 7 demonstrates this setup.

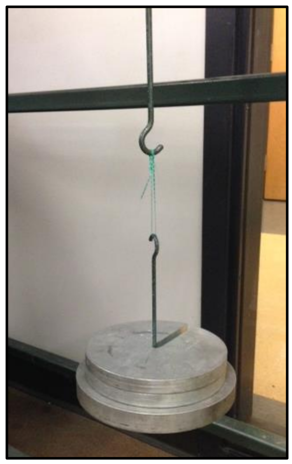

Figure 7: Reinforcement Testing Setup

The final mix exceeded the team's goals of creating a strong and innovative mix. The combined strength of *Spirit's* stucco fiberglass, Fibermesh® 150 reinforcements and concrete mix has created a unique, competition-ready product.

Construction

The main goals that the team wanted to implement during the construction of *Spirit* included efficient quality control, enforced safety procedures, and accurate reinforcement placement.

The mold that was utilized for the casting of *Spirit* was completed by last year's team. The mold was initially modeled in AutoCAD© by splitting the hull into 15 sections each at 3/4 of an inch thick. After the modeling was completed, the 15 male cross-sections were cut into 3/4 inch thick pieces of plywood which were then placed in a strong back. Next, pinewood strips were nailed into each cross-section and then glued to the surrounding wood strips. Once the glue dried, the nails were removed and the mold was patched, sanded, and waterproofed with a fiberglass resin. The mold was removed from the strong back after the resin cured. The mold was placed in female cross-sections. The inside of the mold was sanded and applied with the fiberglass resin while in the female cross-sections. It was concluded that the strong back could be used for future transportation of the canoe to conferences.

Since the team decided to reuse last year's mold, the primary focus was on quality control. The team explored several ideas on how to properly control the thickness desired per layer. After careful deliberation, two methods were decided upon. One method included cutting down pins to the lengths that would reflect the desired thickness per layer. The pins were cut down to 1/8 of an inch, 1/4 of an inch, and 1/2 of an inch long. Four of each sized pins were made so that on pour day, others could assist in checking the thickness periodically. The second method included calculating how much concrete would be needed per layer. It was measured that approximately 49 pounds of concrete was needed for the first layer as well as the second layer and 98 pounds was needed for the final layer. These estimated batch weights did not include the material needed for the bulkheads and ribs.

Pour day was set for February 8th and with the help of volunteers from NAU's own ASCE chapter and the Rocky Mountain Research employees lending the team its facility, it was a success.

Pre-construction tasks began the day before casting day. The tasks included measuring out the quantities of concrete needed per layer and separating them into buckets, purchasing the necessary personal protective equipment, and preparing all tools for transport from the school to the facility.

On casting day, a form release chemical was applied to the inside of the mold in a thin layer. During this process, all volunteers had to read and sign a safety sheet that was written by the team. The volunteers were then told the desired depth for the first layer of concrete that was to be applied and then broken down into teams. Three other volunteers assisted in thickness checks using the pins, two volunteers helped the concrete lead in mixing and distributing the concrete, all others assisted in the application of the concrete.

The first layer was applied by hand while constantly being checked with the pins. The layer was smoothed using trowels. Figure 8 depicts the careful application of concrete.

Figure 8: Application of first 1/8 inch layer

The first layer achieved the desired thickness of 1/8-inch. After this first layer was applied, the first layer of fiberglass mesh was placed on top of that concrete. The reinforcement lead cut down the stucco fiberglass mesh to fit the shape of the canoe. Spliced mesh pieces were strategically placed within the canoe so as to ensure that lateral cracking would not occur due to poor placement. To achieve this, spliced reinforcement were not placed in areas where the max stresses were predicted to occur. Furthermore, a 6 inch overlap between reinforcement layers was recommended to help reduce any risk of cracking due to inadequate placement of reinforcement. Figure 9 shows a 6 inch overlap installed into the canoe.

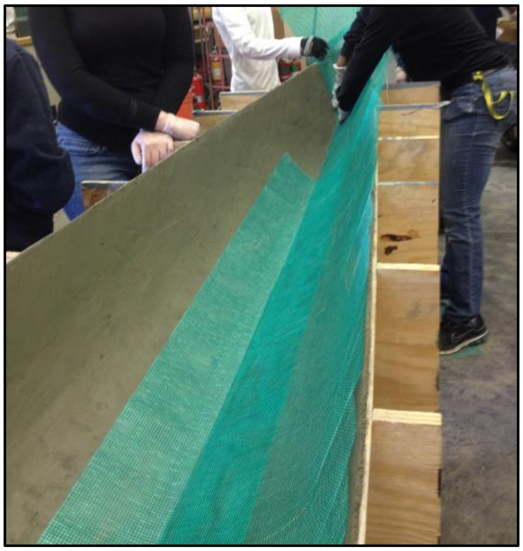

Figure 9: Reinforcement with 6 inch overlap

The open areas within those overlapped sections were lined up to allow for the second layer of concrete to bond with the first layer.

The team worked quickly when applying the fiberglass mesh in order for bond between the layers to be successful. The second layer of concrete was then applied and worked by hand to bond with the first layer of concrete. After completion of the second layer, the second layer of reinforcement was added in a similar fashion. The second layer was also spliced but placed away from the first splice overlaps and maximum stress locations.

Finally, 1/4 inch layer was applied to reach our goal thickness of 1/2 an inch. The layer was worked by hand to ensure bonding between layers. After completion, the top layer was smoothed with trowels with any excess amounts of concrete removed. During this process, ribs were placed and shaped in the appropriate locations. The gunwales were kept at 1/2 inch thickness.

The bulkheads were completed using a unique process. The bulkheads were formed using two solid pieces of foam, one to form the inside face of the bulkhead and the other two form the top of the bulkhead. Once concrete was applied to the form and allowed to cure for 7 days, a hole was drilled and spray foam was used to fill the cavity formed by the foam boards. With the foam boards and concrete in place, the expansion of the foam spray was controlled and excess expansion material was allowed to discharge from the drilled hole.

Once all concrete was placed, a black tarp was used to create a curing tent. A cold-air humidifier was placed inside the tent to allow the canoe to wet cure. Additionally, the team sprayed down the canoe with water every day during the wet curing process. *Spirit* was allowed to wet cure for 21 days and dry cure for 7 days.

After the canoe cured for the projected amount of time, the canoe was removed from the mold. Any holes found within the canoe were then patched. The canoe was then sanded until the surface was smooth. Water based stains were applied to create a blue to gold gradient on *Spirit* with the help of a Flagstaff local artist as well as the NAU art department. A lumberjack representing the courageous spirit of the team was painted on the inside of the canoe. Finally, two even coats of sealant were applied to *Spirit's* surface.

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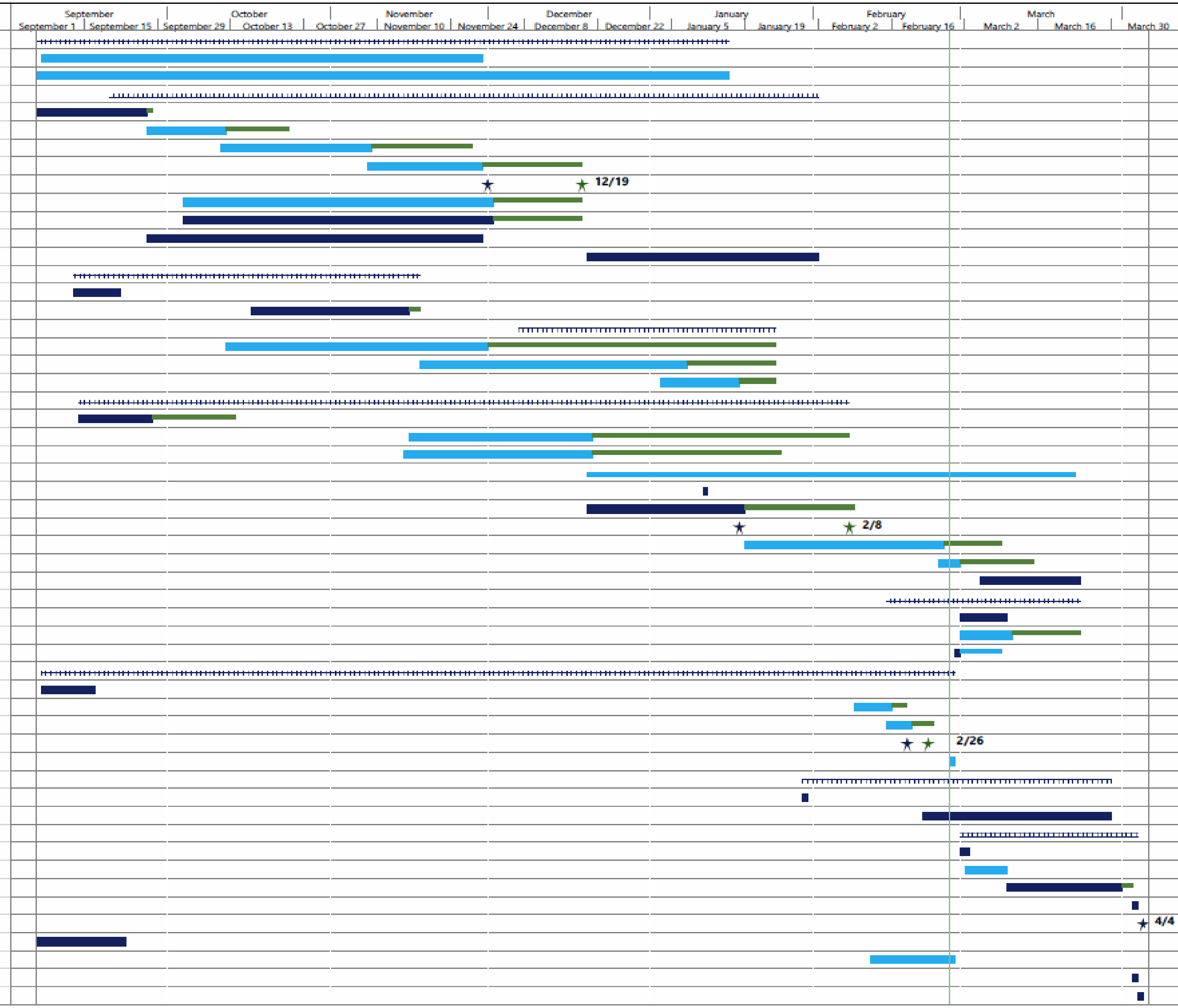
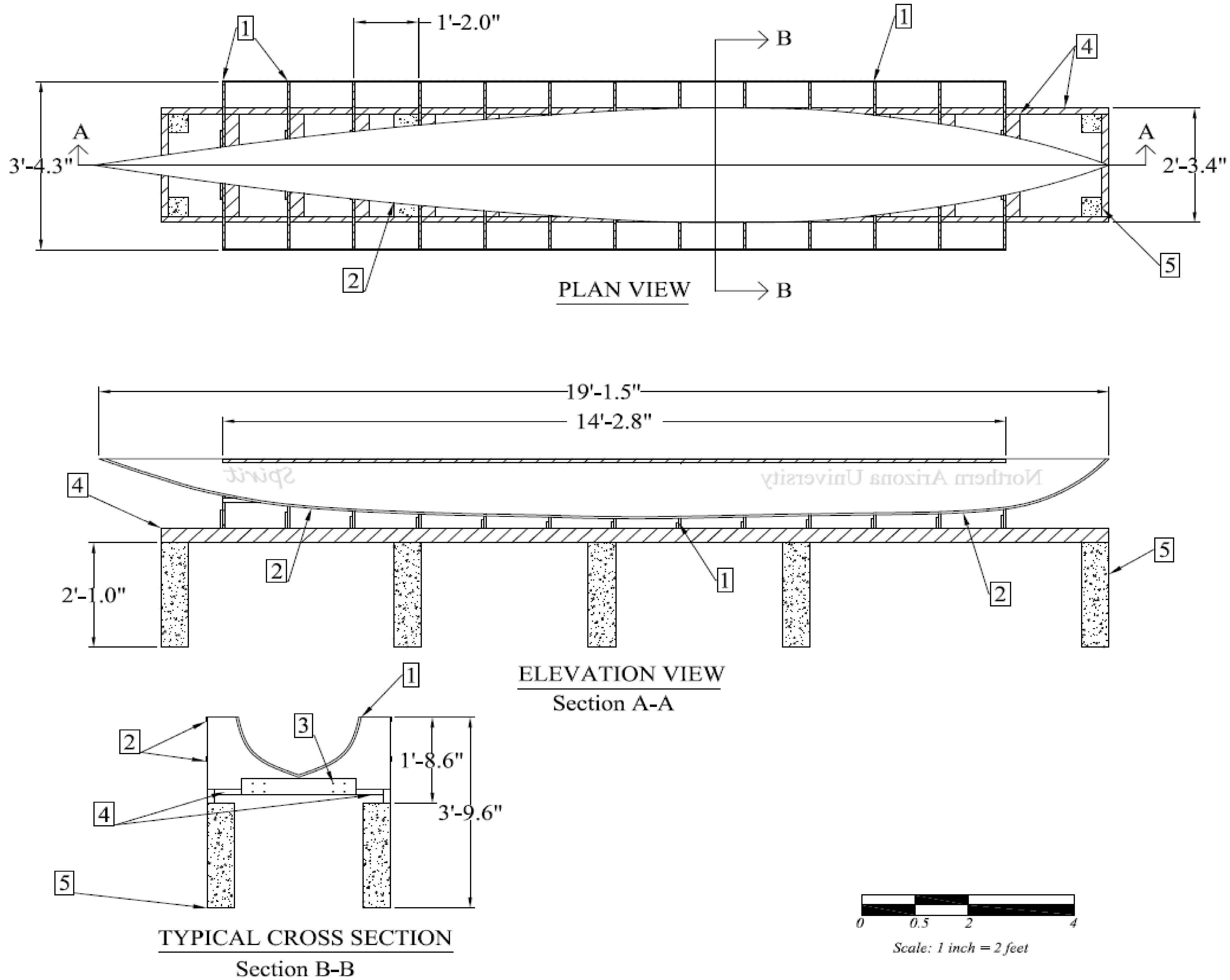
ID	Task Name	Baseline Start	Baseline Finish	Actual Start	Actual Finish
1	**1 Fundraising and Facility**	**Fri 9/6/13**	**Fri 11/29/13**	**Fri 9/6/13**	**Wed 1/15/14**
2	1.1 Fundraising	Sat 9/7/13	Fri 11/29/13	Sat 9/7/13	Fri 11/29/13
3	1.2 Acquiring Facility	Fri 9/6/13	Wed 1/15/14	Fri 9/6/13	Wed 1/15/14
4	**2 Concrete Mix Design**	**Fri 9/6/13**	**Wed 12/18/13**	**Fri 9/20/13**	**Sat 2/1/14**
5	2.1 Research	Fri 9/6/13	Thu 9/26/13	Fri 9/20/13	Fri 9/27/13
6	2.2 Preliminary Mixes	Fri 9/27/13	Fri 10/11/13	Wed 9/25/13	Wed 10/23/13
7	2.3 Secondary Mixes	Fri 10/11/13	Fri 11/8/13	Wed 10/23/13	Wed 11/27/13
8	2.4 Final Mixes	Fri 11/8/13	Fri 11/29/13	Wed 11/27/13	Wed 12/18/13
9	2.5 Final Mix Selection	Sun 12/1/13	Sun 12/1/13	Thu 12/19/13	Thu 12/19/13
10	2.6 Compression Tests	Fri 10/4/13	Sun 12/1/13	Tue 9/24/13	Wed 12/18/13
11	2.7 3-Point Test	Fri 10/4/13	Sun 12/1/13	Fri 10/4/13	Wed 12/18/13
12	2.8 Shrinkage Test	Fri 9/27/13	Fri 11/29/13	Tue 9/24/13	Sun 11/10/13
13	2.9 Construction Methods	Fri 12/20/13	Sat 2/1/14	Fri 12/20/13	Sat 2/1/14
14	**3 Hull Design**	**Fri 9/13/13**	**Wed 10/23/13**	**Fri 9/13/13**	**Sun 11/17/13**
15	3.1 Review Existing Hull Design	Fri 9/13/13	Sat 9/21/13	Fri 9/13/13	Sat 9/21/13
16	3.2 Waterline Analysis	Thu 10/17/13	Fri 11/15/13	Fri 10/25/13	Sun 11/17/13
17	**4 Structural Analysis**	**Sat 10/12/13**	**Sat 11/30/13**	**Sat 12/7/13**	**Fri 1/24/14**
18	4.1 Load Analysis	Sat 10/12/13	Sat 11/30/13	Sat 12/7/13	Fri 1/24/14
19	4.2 Finite Element Analysis	Mon 11/18/13	Tue 1/7/14	Sat 12/7/13	Fri 1/24/14
20	4.3 Buoyancy	Fri 1/3/14	Fri 1/17/14	Mon 1/6/14	Fri 1/24/14
21	**5 Reinforcement Design**	**Sat 9/14/13**	**Fri 12/20/13**	**Sat 9/14/13**	**Fri 2/7/14**
22	5.1 Research	Sat 9/14/13	Fri 9/27/13	Sat 9/14/13	Sun 10/13/13
23	5.2 Rib Design	Sat 11/16/13	Fri 12/20/13	Fri 12/20/13	Fri 2/7/14
24	5.3 Reinforcement Material/Layers	Fri 11/15/13	Fri 12/20/13	Fri 12/20/13	Sat 1/25/14
25	**6 Canoe Construction**	**Fri 12/20/13**	**Sat 3/15/14**	**Fri 12/20/13**	**Sat 3/22/14**
26	6.1 Facility Clean-Up	Sat 1/11/14	Sat 1/11/14	Sat 1/11/14	Sat 1/11/14
27	6.2 Concrete Preparation and Safety	Fri 12/20/13	Sat 1/18/14	Fri 12/20/13	Sat 2/8/14
28	6.3 Pouring	Sat 1/18/14	Sun 1/19/14	Sat 2/8/14	Sat 2/8/14
29	6.4 Curing	Sun 1/19/14	Tue 2/25/14	Sat 2/8/14	Sat 3/8/14
30	6.5 Mold Removal, Patching and Sanding	Tue 2/25/14	Fri 2/28/14	Sun 3/9/14	Fri 3/14/14
31	6.6 Staining	Wed 3/5/14	Sun 3/23/14	Fri 3/14/14	Sat 3/22/14
32	**7 Display Construction**	**Fri 12/20/13**	**Mon 3/10/14**	**Sat 2/15/14**	**Sun 3/23/14**
33	7.1 Display Board	Sat 3/1/14	Sun 3/9/14	Sat 2/15/14	Sun 3/9/14
34	7.2 Stands	Sat 3/1/14	Mon 3/10/14	Sat 2/15/14	Sun 3/23/14
35	7.3 Cross Section Display	Fri 2/28/14	Fri 2/28/14	Sat 3/8/14	Sat 3/8/14
36	**8 Design Report**	**Sat 9/7/13**	**Fri 3/28/14**	**Sat 9/7/13**	**Thu 2/27/14**
37	8.1 Theme Development	Sat 9/7/13	Mon 9/16/13	Sat 9/7/13	Mon 9/16/13
38	8.2 Rough Draft	Sun 2/9/14	Sat 2/15/14	Wed 2/12/14	Tue 2/18/14
39	8.3 Peer Edits/Revisions	Sat 2/15/14	Wed 2/19/14	Tue 2/18/14	Sun 2/23/14
40	8.4 Final Report	Wed 2/19/14	Mon 2/24/14	Sun 2/23/14	Wed 2/26/14
41	8.5 Mail	Thu 2/27/14	Thu 2/27/14	Thu 2/27/14	Thu 2/27/14
42	**9 Paddling**	**Wed 2/19/14**	**Sun 3/30/14**	**Thu 1/30/14**	**Sat 3/29/14**
43	9.1 Recruitment	Thu 1/30/14	Thu 1/30/14	Thu 1/30/14	Thu 1/30/14
44	9.2 Practice/Strength and Conditioning	Sat 2/22/14	Sat 3/29/14	Sat 2/22/14	Sat 3/29/14
45	**10 Oral Presentation**	**Sat 3/1/14**	**Mon 3/17/14**	**Sat 3/1/14**	**Thu 4/3/14**
46	10.1 Discuss Important Points	Sat 3/1/14	Sun 3/2/14	Sat 3/1/14	Sun 3/2/14
47	10.2 Create Slideshow	Sun 3/2/14	Sun 3/9/14	Sun 3/2/14	Sat 3/8/14
48	10.3 Practice/Critique	Mon 3/10/14	Mon 3/31/14	Mon 3/10/14	Wed 4/2/14
49	10.4 Presentation Day	Thu 4/3/14	Thu 4/3/14	Thu 4/3/14	Thu 4/3/14
50	**11 Conference**	**Wed 2/12/14**	**Sat 4/5/14**	**Fri 9/6/13**	**Fri 4/4/14**
51	11.1 Rules and Regulations	Fri 9/6/13	Sun 9/22/13	Fri 9/6/13	Sun 9/22/13
52	11.2 Engineering Notebook	Wed 2/12/14	Thu 2/27/14	Wed 2/12/14	Thu 2/27/14
53	11.3 Display Day	Thu 4/3/14	Thu 4/3/14	Thu 4/3/14	Thu 4/3/14
54	11.4 Races	Fri 4/4/14	Fri 4/4/14	Fri 4/4/14	Fri 4/4/14



Project: *Spirit*
School: Northern Arizona University

Baseline | Actual | Baseline Milestone ★ | Critical Task | Actual Milestone ★ | Summary



Northern Arizona University

Spirit

Formwork

Legend		
No.	**Qty**	**Description**
1	26	3/4" Plywood Sheets
2	13	1/4" Ripped Pine 2 X 4 strips
3	104	3" Screws
4	4	2X6 Cedar
5	8	Recycled 2' Long 6" Dia. Concrete Blocks

General Notes:

- Most of the 1/4" Ripped Pine 2x4 strips were used in construction of the woodstrip mold and are not labeled with the other formwork.

Drawn By: Team *Night Fury*

Modified By: Ariel Suarez

Checked By: Shuo Zhang

Date: 02/20/2014 | Page: 10

Appendix A - References

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Appendix B – Mixture Proportions

			Design Proportions (Non SSD)		Actual Batched Proportions		Yielded Proportions	
YD	Design Batch Size (ft³):							
Cementitious Materials		SG	Amount (lb/yd³)	Volume (ft³)	Amount (lb)	Volume (ft³)	Amount (lb/yd³)	Volume (ft³)
CM1	Portland Cement	3.15	1142.50	5.812	29.45	0.150	1311.75	6.674
	Total Cementitious Materials:		1142.50	5.81	29.45	0.15	1311.75	6.67
Fibers								
F1	Fiber 1	1.10	2.50	0.036	0.06	0.001	2.90	0.042
	Total Fibers:		2.50	0.00	0.06	0.00	2.90	0.04
Aggregates								
A1	Poraver .5-1 mm Abs: 25	0.44	193.75	7.057	5.00	0.182	220.50	8.031
A2	Mortar Sand 12	2.60	479.00	2.952	12.33	0.076	544.31	3.355
	Total Aggregates:		672.75	10.01	17.33	0.26	764.81	11.39
Water								
W1	Water for CM Hydration (W1a + W1b)	1.00	342.75	5.493	11.00	0.176	336.11	5.386
	W1a. Water from Admixtures		33.60		2.70		35.20	
	W1b. Additional Water		342.75		11.00		336.11	
W2	Water for Aggregates, SSD	1.00	105.92		2.73		121.55	
	Total Water *(W1 + W2)*:		448.67	7.19	13.73	0.22	457.66	7.33
Solids Content of Latex, Dyes and Admixtures in Powder Form								
S1	Lime Type S	2.60	84.00	0.518	2.16	0.013	96.43	0.594
	Total Solids of Admixtures:		84.00	0.52	2.16	0.01	96.43	0.59
	Cement-Cementitious Materials Ratio		1.000		1.000		1.000	
	Water-Cementitious Materials Ratio		0.30		0.374		0.256	
	Slump, Slump Flow, *in.*		1.00		1.000		1.000	
M	Mass of Concrete. *lbs*		2350.42		62.73		2633.55	
V	Absolute Volume of Concrete, *ft³*		23.53		0.64		26.03	
T	Theorectical Density, *lb/ft³* = *(M / V)*		99.88		97.73		101.17	
D	Design Density, *lb/ft³* = *(M / 27)*		87.05					
D	Measured Density, *lb/ft³*				94.800		98.180	
A	Air Content, *%* = *[(T - D) / T x 100%]*		12.84		3.00		2.96	
Y	Yield, *ft³* = *(M / D)*		**27**		1		27	
Ry	Relative Yield = *(Y / YD)*				1.000			

Appendix C – Bill of Materials

Material	Quantity	Unit	Unit Cost	Total Price
Concrete Materials				
Material	**Quantity**	**Unit**	**Unit Cost**	**Total Price**
Type 2 Portland Cement	147.7	lb.	$0.13/lb.	$19.20
Type S Lime	10.8	lb.	$0.20/lb.	$2.15
Poraver© (0.5-1mm)	25	lb.	$0.70/lb.	$17.50
Mortar Sand	61.65	lb.	$0.73/lb.	$45.00
Fibermesh® 150	4.8	oz.	$5.00/oz	$24.00
Reinforcement				
Material	**Quantity**	**Unit**	**Unit Cost**	**Total Price**
Green Stucco Fiberglass Mesh	20	yds.	$6.50/yd.	$130.00
Construction				
Material	**Quantity**	**Unit**	**Unit Cost**	**Total Price**
Mold	1	Lump Sum	$852.08	$852.08
Form Oil	0.5	gal.	$33.00/ft.	$16.50
Styrofoam	3.2	cu. ft.	$6.93/ cu. ft.	$22.17
Finishing				
Material	**Quantity**	**Unit**	**Unit Cost**	**Total Price**
Water Based Stain	1.5	gal.	$35.40/gal.	$53.10
Sealer	2	gal.	$25.00/gal.	$50.00
Total Production Cost				$1,231.70