THE FLYING TIGER

Clemson Concrete Canoe Team
ASCE National Concrete Canoe Competition
Montreal, Quebec, Canada
June 19–21, 2008

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Table 1: Project Specifications

Shell Mix (Outer Layers)		
Compressive Strength	3700 psi (25.51 MPa)	
Flexural Strength	425 psi (4.13 MPa)	
Unit Weight	63.65 lb/ft^3 (1002 kg/m^3)	
Core Mix (Inner Layers)		
Compressive Strength	3500 psi (24.13 MPa)	
Flexural Strength	550 psi (5.86 MPa)	
Unit Weight	63.65 lb/ft^3 (1002 kg/m^3)	
Rivet Mix (Patch Layer)		
Compressive Strength	4000 psi (27.58 MPa)	
Flexural Strength	200 psi (1.38 MPa)	
Unit Weight	66.77 lb/ft^3 (1070 kg/m^3)	
Reinforcement		
ASR-Resistant Fiberglass Mesh		
Polypropylene Fibers		
PAN-Based Carbon Fibers		
Canoe Specifications		
Name	THE FLYING TIGER	
Weight	183 lbs	83 kg
Length	19.2 ft	5.9 m
Thickness	0.65 in	1.65 cm
Depth	12.5 in	31.8 cm
Beam At Waterline	28 in	71.1 cm
Color	Aged Steel	

EXECUTIVE SUMMARY

Clemson University is situated in the hills of the Blue Ridge Mountains and is located on the shores of Lake Hartwell. It was founded in 1889 by Thomas Green Clemson with the vision to create "a high seminary of learning." Clemson University is home to more than 14,000 undergraduate and 3,000 graduate students. The civil engineering department has over 300 undergraduate and 80 graduate students. The Clemson Concrete Canoe Team (3CT) is comprised of 20 students and one faculty advisor. 3CT has competed in 21 regional competitions and has gone on to the national competition 15 times. These regional titles have led 3CT to 12 Top-5 placements including three national championships in 1999, 2000, and 2002.

Following eleven months of planning, research, testing, construction, and training, 3CT is proud to present **THE FLYING TIGER** (Table 1) at the ASCE National Concrete Canoe Competition in Montreal. This year's canoe incorporates several new and innovative features. A pre-tensioned system using Tensylon® tendons was incorporated in the design to increase the strength of the gunwales. The concrete mix incorporated an ultra-fine Class F fly ash to increase compressive strength and reduce alkali-silica reaction (ASR). Thermal imagery was used to ensure that the canoe was properly hydrated and cured.

This year's theme pays homage to the WWII 1st American Volunteer Group (AVG) stationed in China before the bombing of Pearl Harbor. The AVG was composed of only volunteers and was one of the fiercest air fighter groups in the Pacific theater. The tiger teeth on the front of the canoe are a direct take of the signature markings found on the P-40's that the AVG flew in.

This year, 3CT is proud to commission **THE FLYING TIGER**.

HULL DESIGN

A balance of several factors is needed in order to design a high performance hull. Straight-line speed is needed in the sprints and maneuverability is crucial in the slalom. In the past, 3CT focused heavily on maneuverability at the expense of speed. For this year, 3CT developed a hull geometry that balanced both straight line speed and maneuverability.

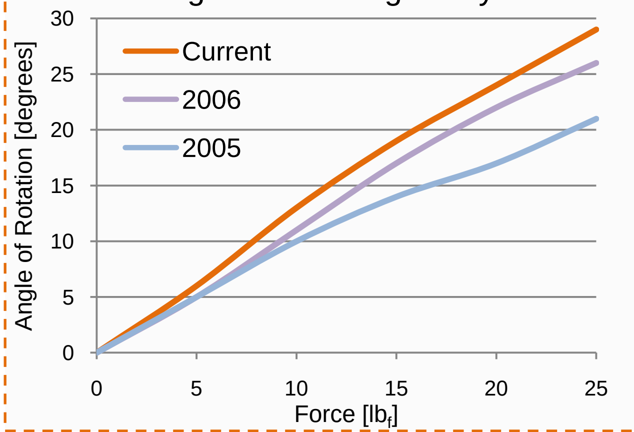
By examining last year's hull, CLEMSON NEVER DIES, it was determined that minor modifications could be made to produce a high performance canoe design. 3CT used hull design software (Prolines 7) that emphasized laminar flow over turbulent flow. This program also helped to minimize the drag forces. 3CT took into account both wave and frictional drag forces to optimize the modifications to last year's hull design.

The Prismatic Coefficient (C_P) was examined carefully to aid in the reduction of both types of drag forces. The C_P is a ratio of the cross sectional area change along the length of the canoe to the displacement volume. It is used as a gauge of the fineness of the ends of a canoe. Typical canoes traveling at speeds of 6 to 8 knots have C_P values ranging from 0.59 to 0.65 (Guillemot). A canoe with a lower C_P will have sharper ends and will perform better at lower speeds (Guillemot). A canoe with high C_P values will have broad ends and will perform better at higher speeds (Guillemot). Because there are speed variations between the sprint and slalom courses, 3CT chose a C_P of 0.60.

To specifically reduce frictional drag forces, 3CT kept the curved bottom hull from last year which effectively lowered the wetted surface area. In order to decrease the wave drag, which is the dominate force acting on canoes traveling at or around 6 knots (Rosen), the length to beam ratio (L/B) was optimized. An optimal L/B ratio is 8.12 (Rosen) and **THE FLYING TIGER** had an L/B ratio of 7.81.

In order to increase turning ability, 3CT examined previous canoes to find areas of improvement. Three canoes, each with significant differences in hull geometry, were examined and their turning ability was quantified. This was done by measuring the canoe's angle of rotation after a load was applied (Figure 1). It was decided that by adding slight rocker in both the bow and stern, the turning ability could be increased without sacrificing straight line stability. Rocker raises the bow and stern from the lateral plane of the canoe. During a turn, the canoe's wetted surface area is decreased. Bow rocker was set at 1 inch and stern rocker was set at 1.5 inches.

Figure 1: Turning Ability



3CT's 2006 canoe experienced significant water gain during the races. This was due to a low depth at the midpoint. To correct this problem and allow the paddlers to execute a proper stroke, 3CT increased the depth by 3 inches.

After comparing this year's hull design with previous years' (Table 2), 3CT was ready to proceed to the analysis phase.

Table 2: Current and Previous Hull Specs

Hull Year	2005	2006	Current
Length	21.4 ft	18.8 ft	19.2 ft
Depth at Midpoint	12 in	9.5 in	12.5 in
Beam at Waterline	26 in	32 in	28 in
Prismatic Coefficient	0.53	0.60	0.60
Length to Beam Ratio	8.86	6.00	7.81

ANALYSIS

Upon completion of the hull design, theoretical and experimental analyses were used to determine the structural and mix design parameters required to build a championship worthy canoe.

The design program CONCAD was used to determine the minimum compressive strength of the concrete and the minimum modulus of elasticity of the reinforcement. The program treated the sides of the canoe as reinforced beams, and calculations indicated that a minimum compressive strength of 1500 psi and a minimum modulus of elasticity of 1000 ksi were needed in order to provide adequate strength. In addition, a minimum flexural strength of 400 psi was set to prevent hairline cracking. This value was based on analysis of previous canoes. These strength requirements had a factor of safety (FS) of 1.5 applied to them.

With a baseline set, different paddling combinations were examined to determine the most stressful condition that would be exerted on the canoe. A shear and moment diagram was used to examine various paddler arrangements. A maximum shear (231 lb) and maximum moment (9681 in-lb) occurred during the three person loading condition (Figure 2). The calculations assumed that the paddlers were point loads of 180 lbs each and used an estimated canoe weight of 190 lbs.

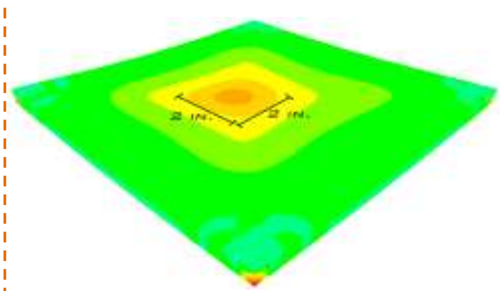
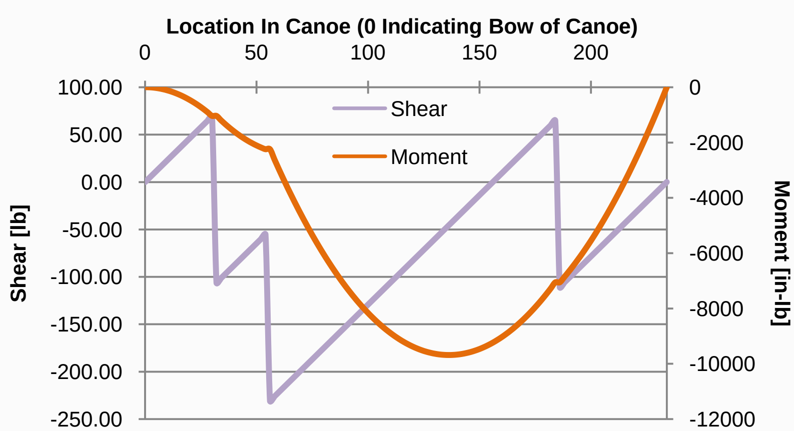


Figure 3: Finite Element Analysis

After the basic structural analysis was completed, 3CT proceeded to conduct a finite element analysis (FEA) of the knee area, as this is the location of most concentrated force (Figure 3). A 14 in. by 14 in. plate was modeled using 1176 shell elements and a knee load of 180 lb_f was applied. The FEA used the minimum compressive strength of 1500 psi and an estimated thickness of 0.6 inches to calculate a required composite strength of 1000 psi.

3CT also conducted experimental analysis to determine the forces acting on the gunwales during racing conditions. A previous canoe was outfitted with strain gauges to measure deflection forces during paddling and turns. By analyzing this data and applying the FS, 3CT determined that 12 pretensioned tendons, tensioned to 46 lbs each, would allow the gunwales of the canoe to stay in compression and prevent cracking. Tensylon® tendons were chosen due to the weight savings and stability in the concrete.

Figure 2: Three Person Loading Condition



3CT also examined possible bulkhead configurations to ensure that there would be adequate strength and durability. It was determined that encasing foam in concrete provided acceptable strength. In addition, it provided the needed floatation to pass the swamp test.

3CT now had a set of baselines, and the development and testing phase could begin.

DEVELOPMENT AND TESTING

Using the strength baselines from the analysis phase, 3CT began the development and testing of various concrete mixes. In order to maximize efficiency during the development process, the mix design was divided into five phases.

Phase I – Cementitious Materials

3CT began the mix design by looking at various cementitious materials. Mixes with Portland cement, Class C and F fly ash, and silica fume were examined qualitatively based on water demand, set time, and color. A baseline mix with only Portland cement was made in order to make qualitative comparisons. Mixes with silica fume had a relatively high water demand and therefore were eliminated. Mixes made with Class C and F fly ash had only a slight increase in water demand and had adequate set times. Particle sizes were also examined (Figure 4) and a finely ground Class F fly ash, Micron^3, achieved a significant increase of strength as compared to normal size fly ash. In addition, the color of the Class F fly ash mix was more desirable and thus was chosen as the binder complement to the Portland cement.

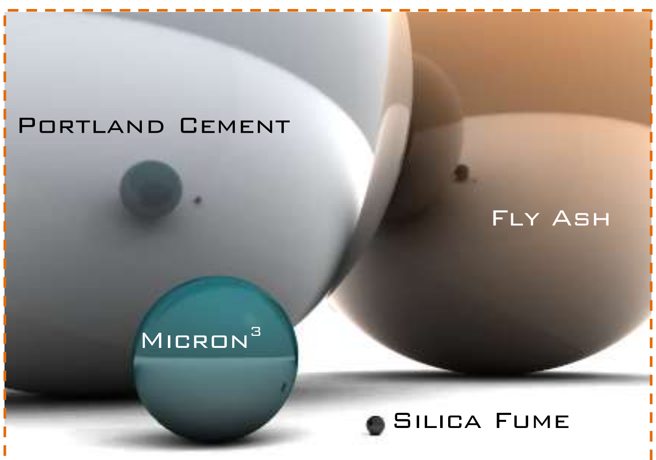


Figure 4: Relative Sizing of Particles

Phase II – Aggregates

Now that 3CT had a general idea of the binder makeup, various aggregates and blends were examined. 3CT looked at expanded shale, vermiculite, glass beads, glass microspheres, and Poraver. Vermiculite was eliminated quickly due to an inconsistent makeup and extreme water demand. Glass beads produced mixes with the highest compressive strength and gave the concrete a glittery appearance. However, the glass beads also produced the densest mixes and were therefore eliminated. From previous years, it was known that a mix of expanded shale could not be made to have a unit weight less than water. Therefore, various blends of expanded shale and Poraver were tested to find a mix that had a unit weight less than water. In addition, several mixes were made with just Poraver to compare with the blend mixes. It was found that the blend mixes were stronger than the all-Poraver mixes. However, the concrete was difficult to sand. Therefore, the all-Poraver mix was chosen because its compressive strength was still greater than 1500 psi, and it sanded smoothly.

Phase III – Water

Due to the restriction of the water to cementitious ratio, this phase of research proceeded quickly. Water to cementitious ratios ranging from 0.3 to 0.39 were tested for workability and strength. The maximum strength was found at a water to cementitious ratio of 0.33. However, workability was extremely poor. The best workability was achieved using a water to cementitious ratio of 0.39 with only a moderate decrease in strength. Because workability is crucial to proper placement, a water to cementitious ratio of 0.39 was chosen.

Phase IV – Admixtures

3CT researched various admixtures to fine tune the properties of the mix. Latexes were added at various percentages according to the manufacturer's directions for the purpose of increasing flexural strength. However, the addition of latex caused a decrease in compressive strength. There was no suitable tradeoff between flexural strength increase and compressive strength decrease and latexes were eliminated from the mix design. Due to the restriction on the water to cementitious ratio, a full range water reducer (FRWR) admixture was tested to increase the workability of the mix. The FRWR was added at a dosage of 2.681 fl oz/cwt and this met the manufacturer's suggested dosage for a Type-A application in accordance with ASTM C494. This addition increased workability while also increasing the compressive strength.

Phase V – Reinforcement

3CT examined CLEMSON NEVER DIES to find out the source of the reinforcement breakdown that caused structural failure. It was determined that the mesh reinforcement used had a low bonding strength with the concrete. This year, 3CT looked at various reinforcement meshes that had surface features that promoted good adhesion to the mix. Meshes of Technora®, carbon fiber, fiberglass, and a hybrid Kevlar®/fiberglass were tested for tensile strength and modulus of elasticity (Table 3).

Table 3: Mesh Strength Test Results

Mesh	ASTM D5034 Tensile [lb_f]	Modulus of Elasticity [ksi]
Technora®	306	10,520*
Carbon Fiber	263	34,000*
Fiberglass	119	1,305
Hybrid	450	10,200*

*Data from MTDS

The hybrid mesh was eliminated because it did not exceed 20% open area. Carbon fiber meshes were unusable due to stiffness. The Technora® mesh met all requirements of the design criteria. However, it was a laminated mesh that had extremely low puncture resistance. The remaining fiberglass mesh was chosen as the primary reinforcement and had a nominal open area of 72%. Qualitative bonding tests were done by constructing plates of identical thickness and layout as the canoe and examining for any delamination. The chosen fiberglass mesh had superior bonding strength compared to last year's reinforcement. In addition, it was coated by the manufacturer to resist ASR.

Fibers were researched for use as secondary reinforcement that would increase the tensile and flexural strength of the concrete. Three types of fibers were examined: carbon, polyethylene, and polypropylene. Since 3CT was staining the canoe with an acid stain, polyethylene fibers were eliminated because of their instability in acidic conditions. 3CT chose to use both the carbon and polypropylene fibers. The carbon fibers, while stronger than polypropylene, experience brittle fracture at the yield stress. However, polypropylene fibers are visco-elastic and undergo plastic deformation before failure. This allows the concrete to continually absorb stress after the failure of the carbon fibers.

With all five phases complete, 3CT had three mixes that exceeded the requirements from the structural analysis (Table 4). Because the Rivet mixes were used only for patching, the lack of flexural strength was not expected to be a problem. The two structural mixes, *Core* and *Shell*, both had unit weights of 63.7 lb/ft^3 (ASTM C138) while the patch mix, Rivet, had a unit weight of 66.8 lb/ft^3 (ASTM C138). 3CT was now ready to construct THE FLYING TIGER.

Table 4: Mix Characterization

Mix	Compressive Strength (ASTM C109) [psi]	Flexural Strength (ASTM C78) [psi]
Baseline	830	610
Requirement	1500	400
Core	3500	550
Shell	3700	425
Rivet	4000	200

CONSTRUCTION AND PROJECT MANAGEMENT

With a final mix and hull design in hand, 3CT proceeded to construct the canoe. The construction process was divided into four phases: form construction, prototype placement, canoe placement, and finishing.

Phase I – Form Construction

The canoe hull was only slightly modified from last year's design and form construction proceeded faster than scheduled. 3CT used a computer numerically controlled (CNC) router to cut 18 rib sections. These sections were bolted one foot apart to a sturdy table and insulation foam was placed in between each rib. The foam was sanded smooth and coated with a layer of plaster to provide durability.

Phase II – Prototype Placement

With a completed form, 3CT could place a prototype canoe. The prototype was made of Kevlar®, fiberglass, and carbon fiber embedded in a vinylic resin. The prototype allowed 3CT to practice in a canoe nearly identical to the real canoe and to become accustomed to its unique handling characteristics.

Phase III – Canoe Placement

Prior to placement, all cementitious materials and aggregates were pre-batched to ensure quality control and to expedite the placement process. The pre-batched materials were sealed in air-tight containers to protect against water absorption. The form was covered with a heat shrink polymer to provide an easy release of the canoe after curing. 3CT utilized a *Core*-and-*Shell* construction scheme for placement. The *Core* and *Shell* mixes are nearly identical except that the *Core* mix has polypropylene fibers added to it. These fibers were not added to the *Shell* mix to allow for easier finishing. Four layers of concrete with alternating layers of fiberglass reinforcement were placed on the form. The first three layers of concrete were placed approximately $^{1}/_{16}$ of an inch thick. The last layer was placed approximately ¼ of an inch thick. In between the middle two layers, 12 pre-tensioned tendons were placed (Figure 5). The tendons were tensioned to 46 lb_f each. This entire process took 4 hours and 28 minutes and was consistent with previous placement times.

Figure 5: Construction Model

Phase IV – Finishing

The canoe was allowed to cure for 28 days. Then the tendon tension was released and the canoe was removed from the form. Once removed from the form, 3CT began sanding the canoe with 180 grit sandpaper. The sanding continued for approximately two months. During this time, the grit of the sandpaper was gradually increased from 180 to 1000 to produce an extremely smooth finish. In addition, patch mixes were also placed to smooth out any imperfections that had arisen from placement. The bulkheads were then placed by inserting foam into each end of the canoe and encasing it in concrete. Once the canoe had a smooth finish, 3CT acid stained the aged steel texture and iconic tiger teeth onto the outside of the canoe with polymer brushes as recommended by the manufacturer. The canoe was then sealed with two coats of sealer applied by roller brushes as recommended by the manufacturer. After the sealer had cured, the name decals were applied.

CONSTRUCTION AND PROJECT MANAGEMENT

Managing a project of this magnitude requires solid leadership and excellent teamwork. Two project managers were selected based on their years of experience and desire to lead an effective team. In previous years, it had been noticed that a dual leadership structure was the most efficient. The project managers appointed team leaders to different areas of the project in order to distribute the workload. The team leaders, in turn, place new members in areas of interest to them. In this way, an organizational structure was established (Page 7).

Following the establishment of an organizational structure, a schedule was created. 3CT examined previous schedules in order to find areas of time savings. It was determined that the most time could be saved in areas of form construction and finishing (Table 5). To save time in form construction, 3CT used a CNC router to cut the rib sections. To save time during the finishing process, the *Core*-and-*Shell* scheme was used to reduce holes caused by the polypropylene fibers.

Table 5: Work-hour Distribution

Task	This Year [hrs]	Last Year [hrs]
Hull Development	54	56
Mix Development	148	158
Form Construction	68	141
Finishing	175	277
Paddling	256	223

Upon the completion of the schedule, a critical path was identified (Page 8). Some of the critical path activities included form construction, concrete analysis, placement, and sanding. In addition, several milestones were set such as completion of the FEA, placement, and technical paper submission. These were chosen based on their importance of proceeding to the next part of the project.

Safety and quality control are also crucial to constructing a championship worthy canoe. All team members were instructed on the safety precautions of all equipment and materials used. Gloves, dust masks, and respirators were used whenever toxic materials were handled. Quality control was assured through several means. A custom designed computer program was used to ensure that all mixes met the NCCC rules. During placement, mechanical mixers were used to ensure consistent mixing of each batch. Thermal imagery was used to identify and correct abnormalities during placement (Figure 6). The canoe was placed in a humidity tent kept at 65°F ± 5°F to ensure proper curing.

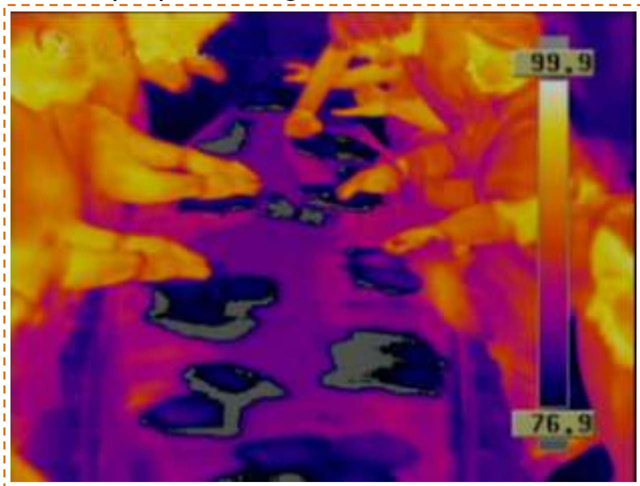
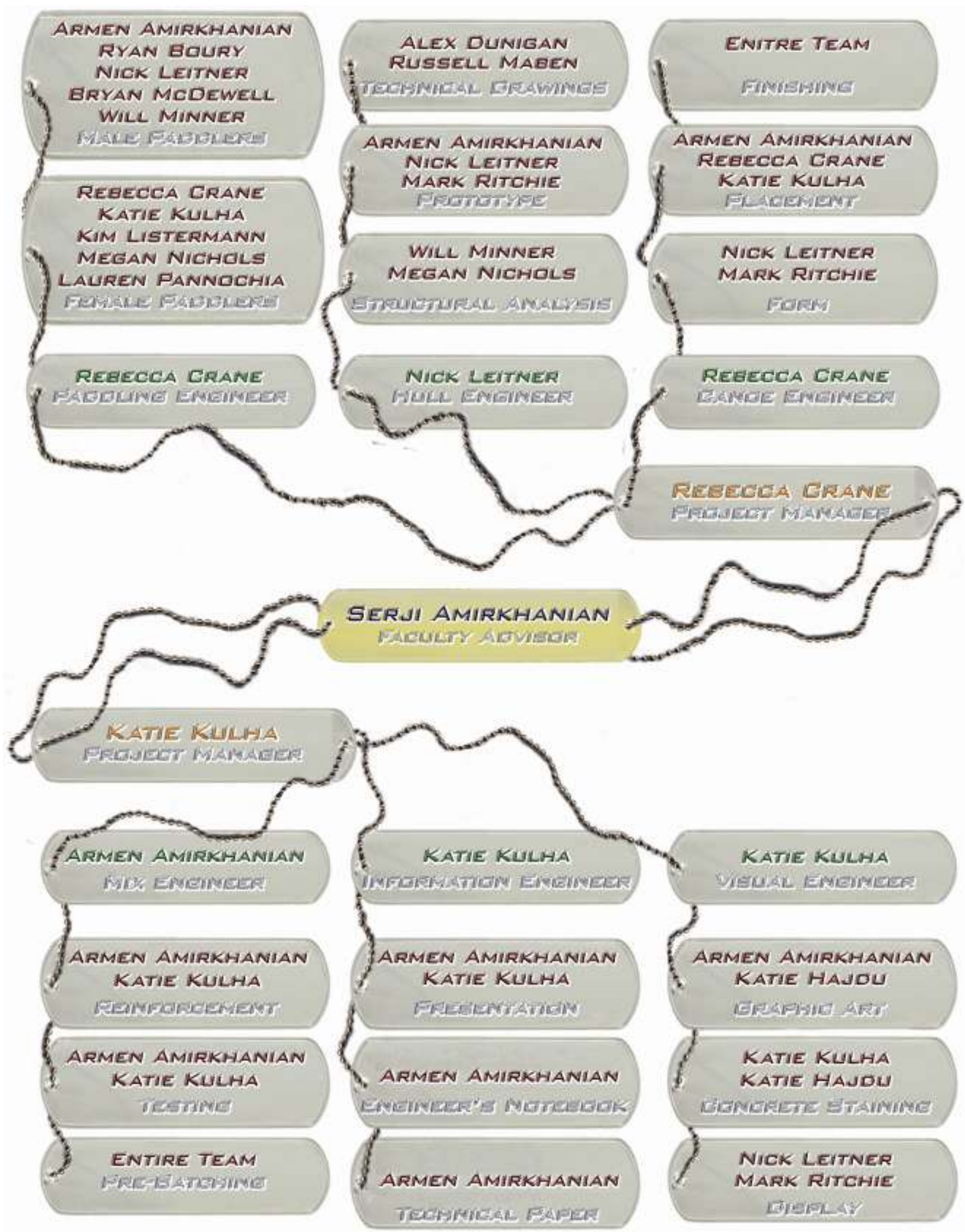


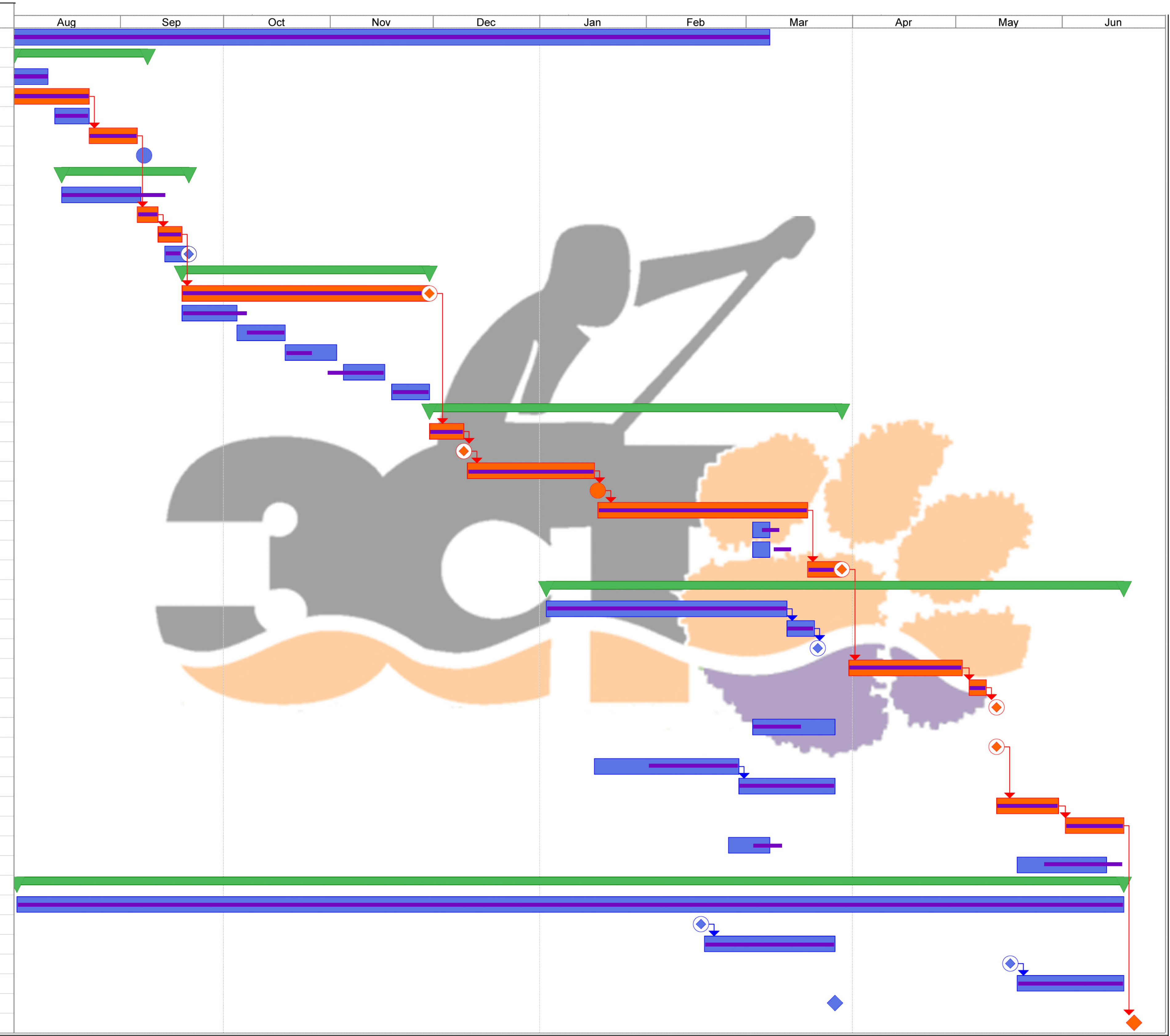
Figure 6: Thermal Imagery of Canoe Placement

A project of this complexity also requires extensive resources and funding. 3CT contacted companies in order to secure donated materials. In this way, all materials used in the construction and finishing of the canoe were donated at no expense to 3CT. The construction of the form required 3CT to purchase medium density fiberboard, foam, and plaster. In addition, travel funds were needed to transport the team and canoe to Montreal. 3CT petitioned and received funding from the Clemson University student chapter of ASCE. With the project brought to a successful completion, 3CT is proud to commission **THE FLYING TIGER**.

ORGANIZATIONAL STRUCTURE

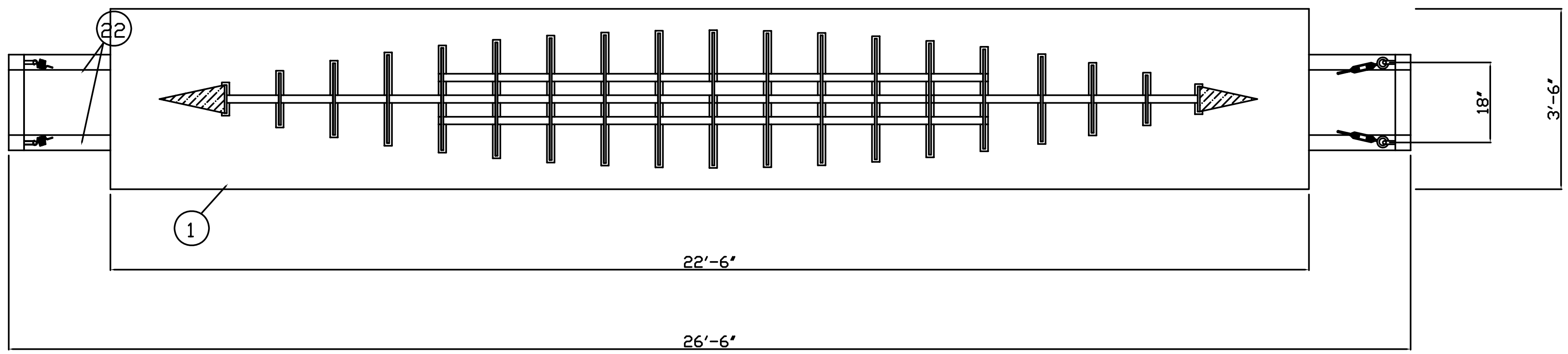


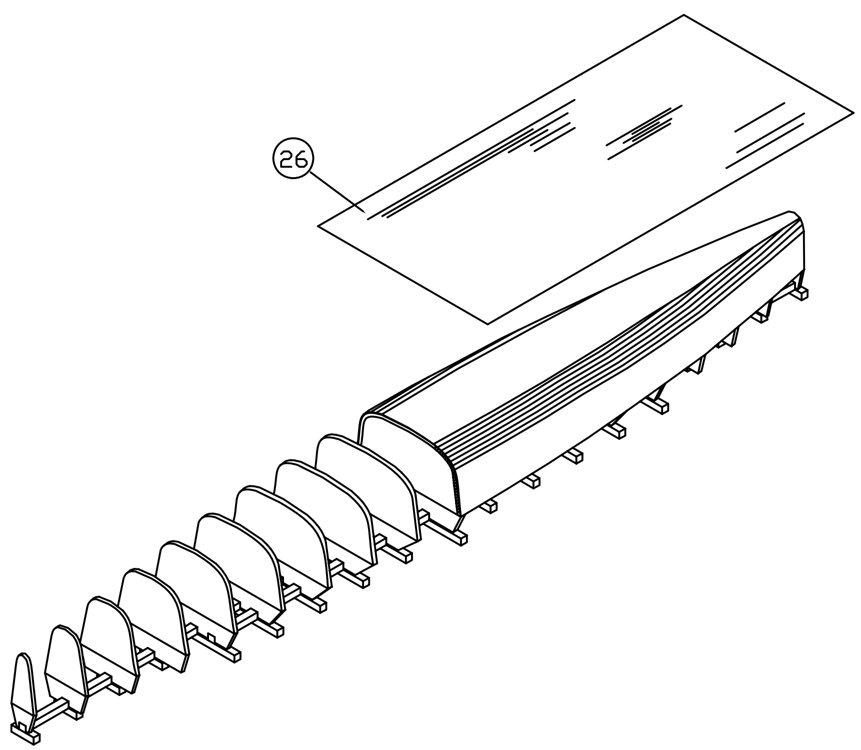
Task Name	Duration	Start	Finish
Recruitment	**163 days**	**Wed 8/1/07**	**Fri 3/7/08**
Hull Design	**29 days**	**Wed 8/1/07**	**Sat 9/8/07**
Research	8 days	Wed 8/1/07	Fri 8/10/07
Design Development	16 days	Wed 8/1/07	Wed 8/22/07
Analysis	8 days	Mon 8/13/07	Wed 8/22/07
Hull Construction	10 days	Thu 8/23/07	Wed 9/5/07
Prototype Construction	1 day	Sat 9/8/07	Sat 9/8/07
Structural Analysis	**28 days**	**Wed 8/15/07**	**Thu 9/20/07**
Research	17 days	Wed 8/15/07	Thu 9/6/07
Canoe Analysis	5 days	Thu 9/6/07	Tue 9/11/07
Concrete Analysis	5 days	Wed 9/12/07	Tue 9/18/07
Finite Element Analysis	5 days	Fri 9/14/07	Thu 9/20/07
Mix Analysis	**52 days**	**Wed 9/19/07**	**Thu 11/29/07**
Material Acquisition	52 days	Wed 9/19/07	Thu 11/29/07
Phase I (Cementitious Materials)	12 days	Wed 9/19/07	Thu 10/4/07
Phase II (Aggregate)	10 days	Fri 10/5/07	Thu 10/18/07
Phase III (Water)	11 days	Fri 10/19/07	Fri 11/2/07
Phase IV (Admixtures)	10 days	Mon 11/5/07	Fri 11/16/07
Phase V (Fibers)	9 days	Mon 11/19/07	Thu 11/29/07
Canoe Construction	**90 days**	**Fri 11/30/07**	**Fri 3/28/08**
Prebatching	8 days	Fri 11/30/07	Sun 12/9/07
Placement	1 day	Mon 12/10/07	Mon 12/10/07
Curing	28 days	Tue 12/11/07	Wed 1/16/08
Removal Of Form	1 day	Thu 1/17/08	Thu 1/17/08
Sanding/Patching	44 days	Fri 1/18/08	Tue 3/18/08
Endcaps	5 days	Mon 3/3/08	Fri 3/7/08
Cross Section	5 days	Mon 3/3/08	Fri 3/7/08
Staining/Sealing/Decals	8 days	Wed 3/19/08	Fri 3/28/08
Documentation	**123 days**	**Thu 1/3/08**	**Wed 6/18/08**
Regionals Technical Paper Drafts	51 days	Thu 1/3/08	Wed 3/12/08
Regionals Technical Paper Final Edit	6 days	Thu 3/13/08	Thu 3/20/08
Regionals Technical Paper Submission	1 day	Fri 3/21/08	Fri 3/21/08
Nationals Technical Paper Drafts	25 days	Mon 3/31/08	Fri 5/2/08
Nationals Technical Paper Final Edit	5 days	Mon 5/5/08	Fri 5/9/08
Nationals Technical Paper Submission	1 day	Mon 5/12/08	Mon 5/12/08
Engineering Notebook	18 days	Mon 3/3/08	Wed 3/26/08
Engineering Notebook Submission (Electronic)	1 day	Mon 5/12/08	Mon 5/12/08
Regionals Presentation Development	31 days	Thu 1/17/08	Wed 2/27/08
Regionals Presentation Practice	20 days	Thu 2/28/08	Wed 3/26/08
Nationals Presentation Development	15 days	Tue 5/13/08	Fri 5/30/08
Nationals Presentation Practice	13 days	Mon 6/2/08	Wed 6/18/08
Regionals Display Construction	10 days	Mon 2/25/08	Fri 3/7/08
Nationals Display Construction	20 days	Mon 5/19/08	Fri 6/13/08
Paddling	**237 days**	**Thu 8/2/07**	**Wed 6/18/08**
Physical Training	237 days	Thu 8/2/07	Wed 6/18/08
Regionals Time Trials	1 day	Sat 2/16/08	Sat 2/16/08
Regionals Combination Practice	28 days	Mon 2/18/08	Wed 3/26/08
Nationals Time Trials	1 day	Sat 5/17/08	Sat 5/17/08
Nationals Combination Practice	23 days	Mon 5/19/08	Wed 6/18/08
Regional Competition: Greensboro, NC	**3 days**	**Thu 3/27/08**	**Sat 3/29/08**
National Competition: Montreal, Canada	**2 days**	**Thu 6/19/08**	**Sat 6/21/08**

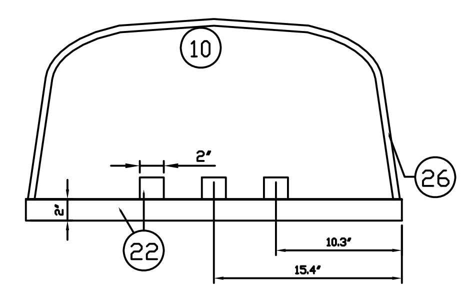


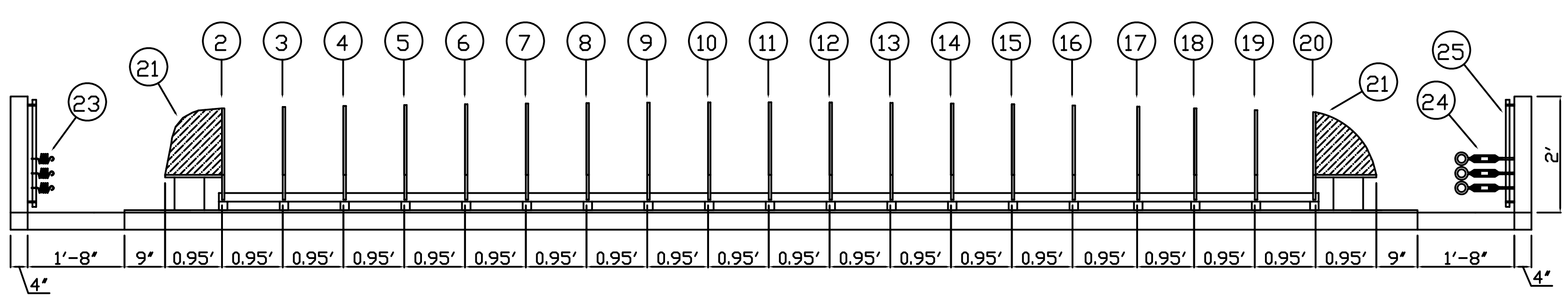
Project: 3CT Project Schedule 2008
Date: 8/1/2007
Revised: 5/1/2008

Task | Critical Task | Milestone | Critical Milestone | Single Day Activity | Critical Single Day Activity | Summary | Final Deadline | Actual Progress









ITEM NO	QTY	PART	DESCRIPTION
1	1	TABLE	3/4"PLYWOOD
2	1	XC-1	1/2" MDF
3	1	XC-2	1/2" MDF
4	1	XC-3	1/2" MDF
5	1	XC-4	1/2" MDF
6	1	XC-5	1/2" MDF
7	1	XC-6	1/2" MDF
8	1	XC-7	1/2" MDF
9	1	XC-8	1/2" MDF
10	1	XC-9	1/2" MDF
11	1	XC-10	1/2" MDF
12	1	XC-11	1/2" MDF
13	1	XC-12	1/2" MDF
14	1	XC-13	1/2" MDF
15	1	XC-14	1/2" MDF
16	1	XC-15	1/2" MDF
17	1	XC-16	1/2" MDF
18	1	XC-17	1/2" MDF
19	1	XC-18	1/2" MDF
20	1	XC-19	1/2" MDF
21	2	END	STYROFOAM END FORM
22	22	XC-BASE	2"x2" PINE
23	24	SPRING	CALIBRATION SPRINGS
24	24	TURN	TURNBUCKLES
25	4	ROD	3/8" STEEL ROD
26	1	PLASTIC	HEAT SHRINK POLYMER

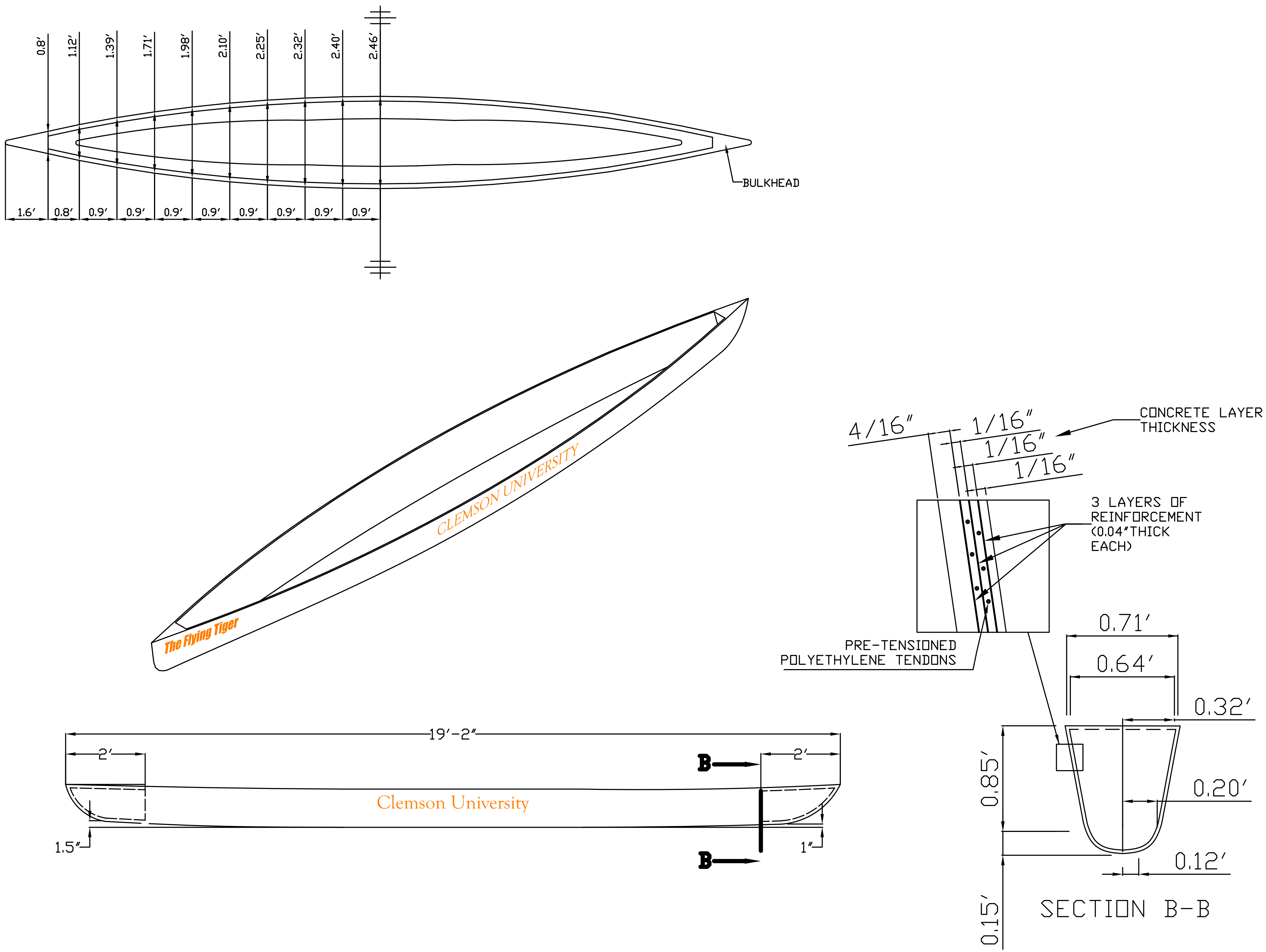
REV. DATE	REV	DESCRIPTION
3/8/08	1	FORMATTING

ENGINEER: RUSSELL MABEN

DRAWN BY: RBM DATE:8/20/07

CHECKED BY: ANA DATE:8/20/07

PROJECT: **The Flying Tiger**



ITEM NO	QTY	UNIT	DESCRIPTION
1	3.2	CF	CONCRETE
2	256	SF	FIBERGLASS MESH
3	230	LF	POLYETHYLENE TENDONS
4	0.37	CF	POLYURETHANE FOAM

REV. DATE	REV	DESCRIPTION

ENGINEER: RUSSELL MABEN

DRAWN BY: RBM DATE: 3/7/08

CHECKED BY: ANA DATE: 3/7/08

PROJECT: **The Flying Tiger**

REFERENCES

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Table B-1: Mixture Proportions

Mixture: Shell (Outer Layers)
Batch Size: 0.041 ft^3

Cementitious Materials	Specific* Gravity	Non-SSD Proportions as Designed: Amount (lb/yd^3)	Non-SSD Proportions as Designed: Volume (ft^3)	Actual Batched Proportions: Amount (lb)	Actual Batched Proportions: Volume (ft^3)	Yielded Proportions: Amount (lb/yd^3)	Yielded Proportions: Volume (ft^3)
1. ASTM C150 White Portland Cement Type I	3.15	497.61	2.530	0.772	0.004	470.65	2.393
2. ASTM C618 Class F Fly Ash	2.53	319.89	2.025	0.496	0.003	302.56	1.916
Total of All Cementitious Materials		817.50	4.555	1.268	0.007	773.21	4.309
Fibers							
1. Carbon	2.90	0.71	0.004	0.001	6.1E-6	0.67	0.004
Aggregates							
1. Poraver 0.5mm - 1mm; Absorption, 20.0 %	0.60	362.55	9.679	0.562	0.015	342.90	9.155
2. Poraver 0.25mm - 0.5mm; Absorption, 20.0 %	0.78	184.83	3.796	0.287	0.006	174.81	3.590
3. Poraver 0.1mm - 0.3mm; Absorption, 20.0 %	0.98	21.33	0.349	0.033	0.001	20.17	0.330
4. Glass Microspheres (Hollow); Absorption, 0.0 %	0.32	14.22	0.712	0.022	0.001	13.45	0.673
Total of All Aggregates		582.93	14.536	0.904	0.023	551.33	13.748
Water							
Batched Water^	1.00	284.35	4.557	0.496	0.008	302.56	4.849
Total Water Added for Aggregate Absorption	1.00	113.74	1.823	0.176	0.003	107.58	1.724
Total Water from All Admixtures§	1.00	0.00	0.000	0.000	0.000	0.00	0.000
Total Water		398.09	6.380	0.672	0.011	410.14	6.573

Admixtures	% Solids	Amount (fl oz/cwt)	Water in Admixture (lb/yd^3)	Amount (fl oz)	Water in Admixture (lb)	Amount (fl oz/cwt)	Water in Admixture (lb/yd^3)
4. Glenium 3030NS ; Density, 8.76 lb/gal	20%	2.681	1.143	0.034	0.000	2.681	1.081

	Non-SSD Proportions as Designed	Actual Batched Proportions	Yielded Proportions
Cement-Cementitious Materials Ratio	0.609	0.609	0.609
Water-Cementitious Materials Ratio	0.348	0.391	0.391
Flow (flow table), Slump, Slump Flow, in.	3.00	2.50	2.50
Air Content, %	6.00	9.62	9.62
Density (Unit Weight), lb/ft^3	66.6	63.7	63.7
Gravimetric Air Content, %		9.62	
Yield, ft^3	27.00	0.041	27.00

* *For aggregates provide ASTM C 127 oven-dry bulk specific gravity.*
^ *Excluding water added for aggregate absorption.*
§ *If impact on water-cementitious materials ratio is less than 0.01 enter zero.*

Table B-2: Mixture Proportions

Mixture: Core (Inner Layers)
Batch Size: 0.041 ft^3

		Non-SSD Proportions as Designed		Actual Batched Proportions		Yielded Proportions	
Cementitious Materials	Specific* Gravity	Amount (lb/yd^3)	Volume (ft^3)	Amount (lb)	Volume (ft^3)	Amount (lb/yd^3)	Volume (ft^3)
1. ASTM C150 White Portland Cement Type I	3.15	496.91	2.527	0.772	0.004	470.08	2.390
2. ASTM C618 Class F Fly Ash	2.53	319.44	2.023	0.496	0.003	302.20	1.913
Total of All Cementitious Materials		816.35	4.550	1.268	0.007	772.28	4.303
Fibers							
1. Carbon	2.90	0.71	0.004	0.001	6.1E-6	0.67	0.004
2. Polypropylene	0.95	2.13	0.036	0.003	5.6E-5	2.01	0.034
Aggregates							
1. Poraver 0.5mm - 1mm; Absorption, 20.0 %	0.60	362.04	9.665	0.562	0.015	342.49	9.144
2. Poraver 0.25mm - 0.5mm; Absorption, 20.0 %	0.78	184.57	3.790	0.287	0.006	174.60	3.586
3. Poraver 0.1mm - 0.3mm; Absorption, 20.0 %	0.98	21.30	0.348	0.033	0.001	20.15	0.329
4. Glass Microspheres (Hollow); Absorption, 0.0 %	0.32	14.20	0.711	0.022	0.001	13.43	0.672
Total of All Aggregates		582.11	14.514	0.904	0.023	550.67	13.731
Water							
Batched Water^	1.00	283.95	4.550	0.496	0.008	302.20	4.843
Total Water Added for Aggregate Absorption	1.00	113.58	1.820	0.176	0.003	107.45	1.722
Total Water from All Admixtures§	1.00	0.00	0.000	0.000	0.000	0.00	0.000
Total Water		397.53	6.370	0.672	0.011	409.65	6.565
Admixtures	% Solids	Amount (fl oz/cwt)	Water in Admixture (lb/yd^3)	Amount (fl oz)	Water in Admixture (lb)	Amount (fl oz/cwt)	Water in Admixture (lb/yd^3)
4. Glenium 3030NS ; Density, 8.76 lb/gal	20%	2.681	1.141	0.034	0.000	2.681	1.079
Cement-Cementitious Materials Ratio		0.609		0.609		0.609	
Water-Cementitious Materials Ratio		0.348		0.391		0.391	
Flow (flow table), Slump, Slump Flow, in.		3.00		2.50		2.50	
Air Content, %		6.00		9.60		9.60	
Density (Unit Weight), lb/ft^3		66.6		63.7		63.7	
Gravimetric Air Content, %				9.60			
Yield, ft^3		27.00		0.041		27.00	

* *For aggregates provide ASTM C 127 oven-dry bulk specific gravity.*
^ *Excluding water added for aggregate absorption.*
§ *If impact on water-cementitious materials ratio is less than 0.01 enter zero.*

Table B-3: Mixture Proportions

Mixture: Rivet (Patch Layers)
Batch Size: 0.038 ft^3

		Non-SSD Proportions as Designed		Actual Batched Proportions		Yielded Proportions	
Cementitious Materials	Specific* Gravity	Amount (lb/yd^3)	Volume (ft^3)	Amount (lb)	Volume (ft^3)	Amount (lb/yd^3)	Volume (ft^3)
1. ASTM C150 White Portland Cement Type I	3.15	541.96	2.756	0.772	0.004	498.92	2.537
2. ASTM C618 Class F Fly Ash	2.53	348.40	2.206	0.496	0.003	320.73	2.031
Total of All Cementitious Materials		890.36	4.962	1.268	0.007	819.65	4.568
Aggregates							
2. Poraver 0.25mm - 0.5mm (Absorption, 20.0 %)	0.78	603.90	12.402	0.860	0.018	555.94	11.417
3. Glass Microspheres (Hollow) (Absorption, 0.0 %)	0.32	23.23	1.163	0.033	0.002	21.38	1.070
Total of All Aggregates		627.13	13.565	0.893	0.020	577.32	12.487
Water							
Batched Water^	1.00	312.79	5.013	0.500	0.008	323.58	5.186
Total Water Added for Aggregate Absorption	1.00	120.78	1.936	0.172	0.003	111.19	1.782
Total Water from All Admixtures§	1.00	0.00	0.000	0.000	0.000	0.00	0.000
Total Water		433.57	6.949	0.672	0.011	434.77	6.968
Cement-Cementitious Materials Ratio		0.609		0.609		0.609	
Water-Cementitious Materials Ratio		0.351		0.394		0.394	
Flow (flow table), Slump, Slump Flow, in.		3.00		2.50		2.50	
Air Content, %		6.00		12.41		12.41	
Density (Unit Weight), lb/ft^3		72.2		66.8		66.8	
Gravimetric Air Content, %				12.41			
Yield, ft^3		27.00		0.038		27.00	

* *For aggregates provide ASTM C 127 oven-dry bulk specific gravity.*
^ *Excluding water added for aggregate absorption.*

GRADATION CURVES AND TABLES

Figure C-1: *Core* And *Shell* Aggregate Gradation Curve

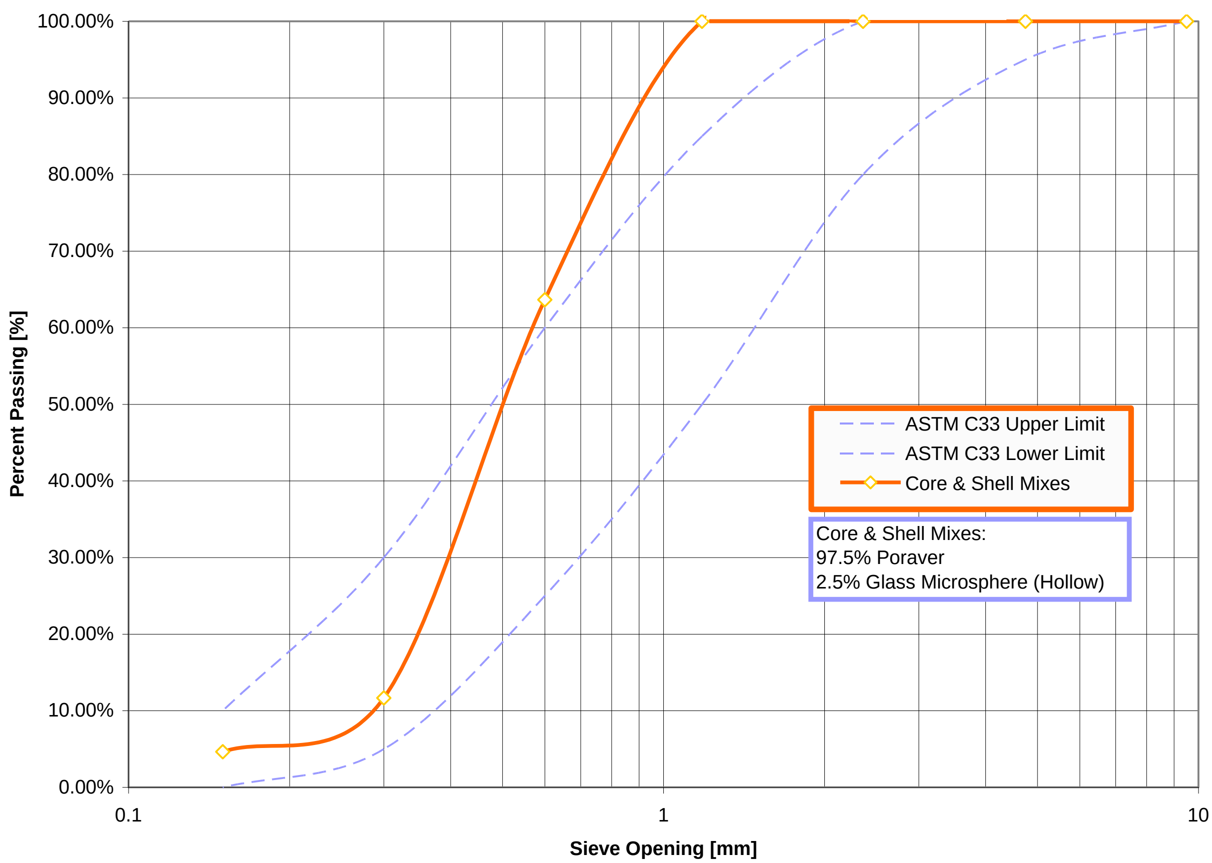

Table C-1: Core And Shell Aggregate

Sample Weight: 500 g
Specific Gravity: Not Applicable
Fineness Modulus: 2.20

Sieve	Diameter [mm]	Weight Retained [g]	Cumulative Weight Retained [g]	Percent Finer [%]
⅜ inch	9.50	0.0	0.0	100.00
No. 4	4.75	0.0	0.0	100.00
No. 8	2.36	0.0	0.0	100.00
No. 16	1.18	0.0	0.0	100.00
No. 30	0.60	181.7	181.7	63.66
No. 50	0.30	260.0	441.7	11.66
No. 100	0.15	35.1	476.8	4.64
Pass 100	--	23.2	500.0	0.00

GRADATION CURVES AND TABLES

Figure C-2: Rivet Aggregate Gradation Curve

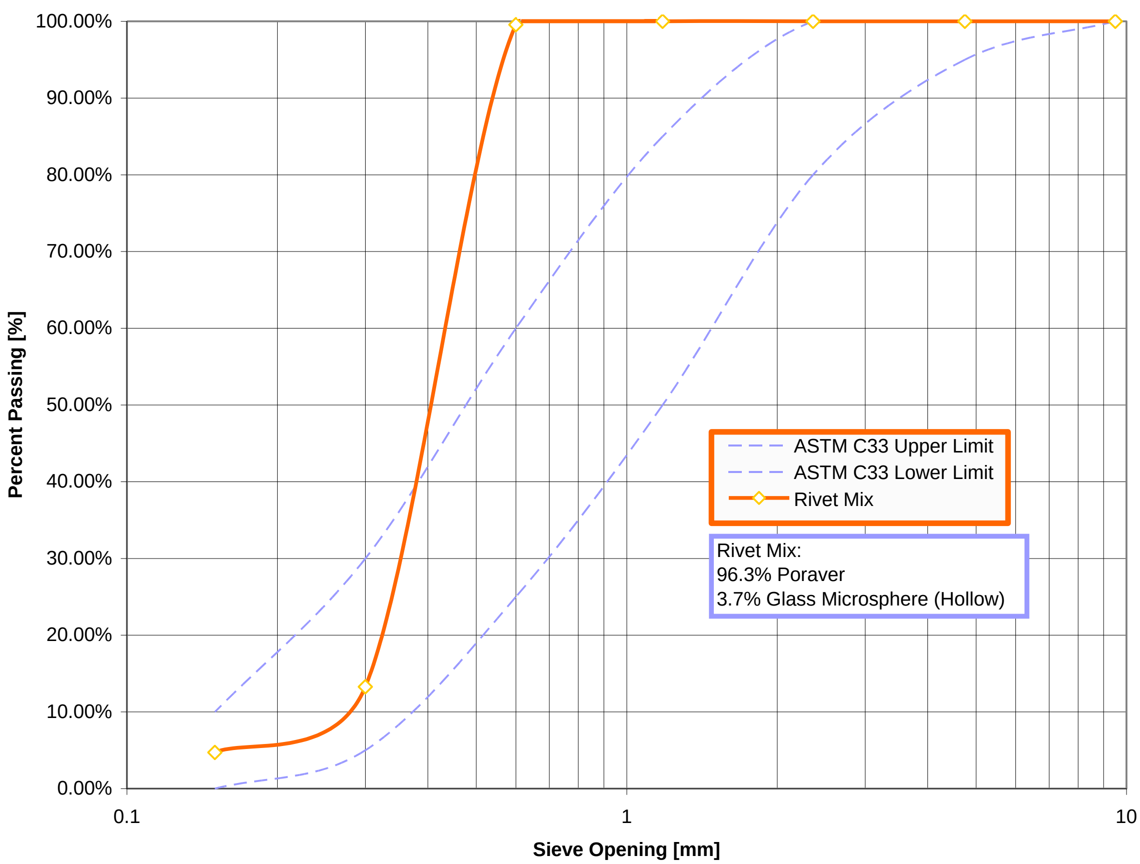

Table C-2: Rivet Aggregate

Sample Weight:	500 g
Specific Gravity:	Not Applicable
Fineness Modulus:	1.82

Sieve	Diameter [mm]	Weight Retained [g]	Cumulative Weight Retained [g]	Percent Finer [%]
⅜ inch	9.50	0.0	0.0	100.00
No. 4	4.75	0.0	0.0	100.00
No. 8	2.36	0.0	0.0	100.00
No. 16	1.18	0.0	0.0	100.00
No. 30	0.60	2.2	2.2	99.56
No. 50	0.30	431.4	433.6	13.28
No. 100	0.15	42.9	476.5	4.70
Pass 100	--	23.5	500.0	0.00

GRADATION CURVES AND TABLES

Figure C-3: Various Aggregate Gradation Curves

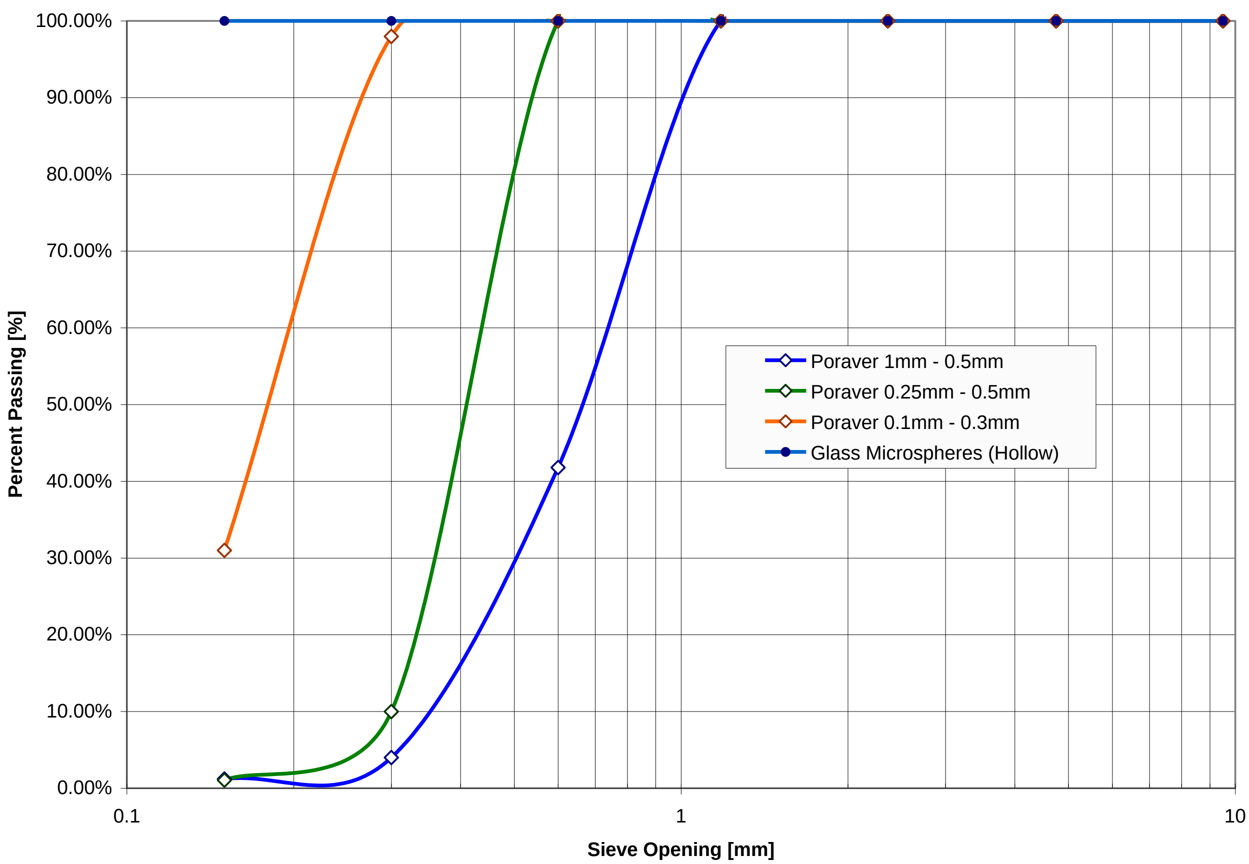

Table C-3: Poraver 1mm – 0.5mm Gradation

Sample Weight:		500 g		
Specific Gravity:		0.60		
Fineness Modulus:		2.53		
Sieve	Diameter [mm]	Weight Retained [g]	Cumulative Weight Retained [g]	Percent Finer [%]
⅜ inch	9.50	0.0	0.0	100.00
No. 4	4.75	0.0	0.0	100.00
No. 8	2.36	0.0	0.0	100.00
No. 16	1.18	0.0	0.0	100.00
No. 30	0.60	291.0	291.0	41.80
No. 50	0.30	189.0	480.0	4.00
No. 100	0.15	14.0	494.0	1.20
Pass 100	--	6.0	500.0	0.00

GRADATION CURVES AND TABLES

Table C-4: Poraver 0.25mm – 0.5mm Gradation

Sample Weight: 500 g
Specific Gravity: 0.78
Fineness Modulus: 1.89

Sieve	Diameter [mm]	Weight Retained [g]	Cumulative Weight Retained [g]	Percent Finer [%]
⅜ inch	9.50	0.0	0.0	100.00
No. 4	4.75	0.0	0.0	100.00
No. 8	2.36	0.0	0.0	100.00
No. 16	1.18	0.0	0.0	100.00
No. 30	0.60	2.3	2.3	99.54
No. 50	0.30	448.0	450.3	9.94
No. 100	0.15	44.5	494.8	1.04
Pass 100	--	5.2	500.0	0.00

Table C-5: Poraver 0.1mm – 0.3mm Gradation

Sample Weight: 500 g
Specific Gravity: 0.98
Fineness Modulus: 0.71

Sieve	Diameter [mm]	Weight Retained [g]	Cumulative Weight Retained [g]	Percent Finer [%]
⅜ inch	9.50	0.0	0.0	100.00
No. 4	4.75	0.0	0.0	100.00
No. 8	2.36	0.0	0.0	100.00
No. 16	1.18	0.0	0.0	100.00
No. 30	0.60	0.0	0.0	100.00
No. 50	0.30	10.7	10.7	97.86
No. 100	0.15	334.5	345.2	30.96
Pass 100	--	154.8	500.0	0.00

GRADATION CURVES AND TABLES

Figure C-4: Glass Microsphere (Hollow) Gradation Curve

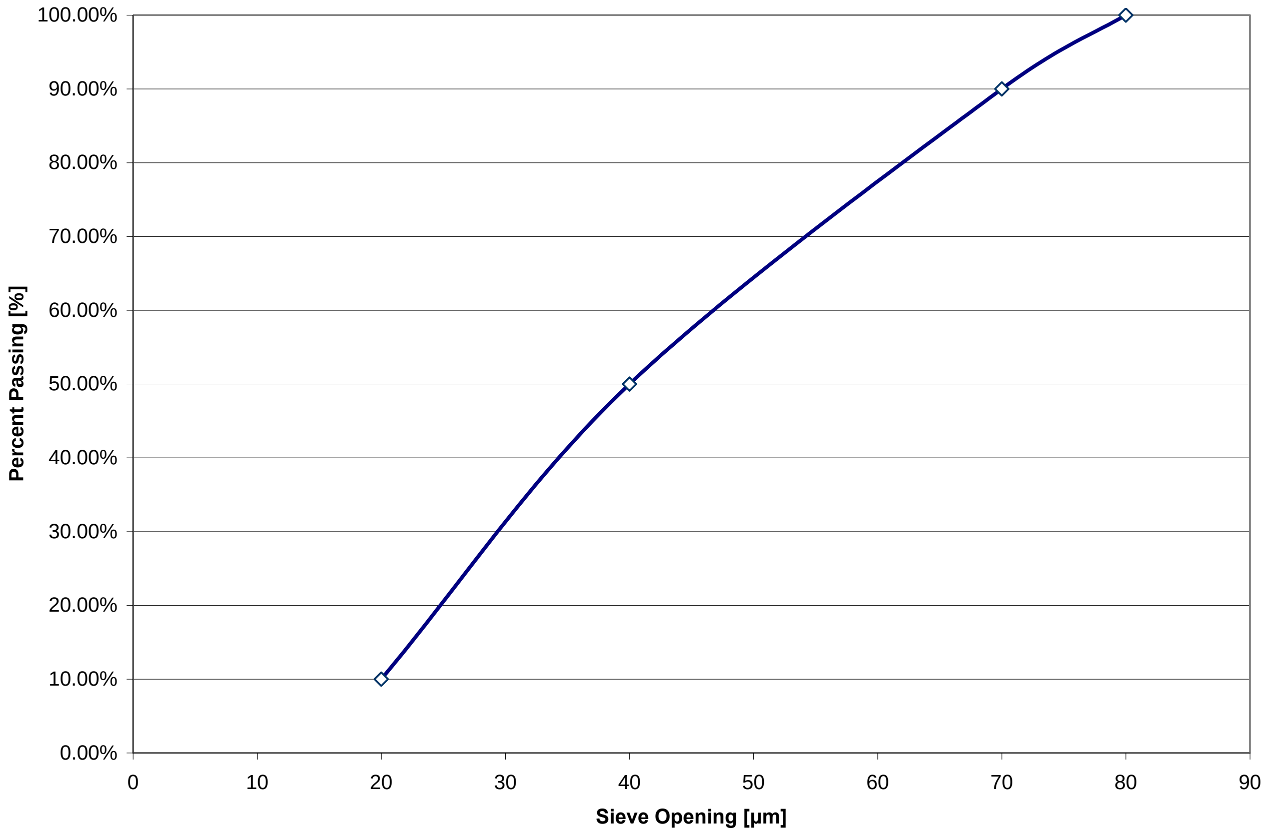

Table C-6: Glass Microsphere (Hollow) Gradation

Sample Weight:	Not Applicable	
Specific Gravity:	0.32	
Fineness Modulus:	Not Applicable	
Size [μm]	**Distribution [Percentile]**	**Effective Top Size [μm]**
70	90th	80
40	50th	
20	10th	
Data based on 3M Quality Control Method 193.0		