Oklahoma State University

2000 Concrete Canoe Team

Grand Slam

1.0 Executive Summary

Lighter, longer, faster, and stronger, Oklahoma State University introduces concrete canoe – *Grand Slam*. It is constructed with 0.31 inch thick lightweight concrete, yielding a compressive strength of 880psi, and a unit weight of 53pcf. *Grand Slam*, reinforced with

10 layers of fiberglass scrim cloth, is the first ever inherently buoyant canoe to leave Stillwater, Oklahoma.
***Grand Slam* measures 20.5 feet long, 11 inches deep, 32 inches wide, and tips the scales at a trim 75 pounds. It is painted black and traditional orange and white finishes highlighting six cross-sectional ribs. The ribs provide lateral stiffness to the elliptical cross-sections of this strategically designed racing machine.**

2.0 Introduction

Oklahoma State University is located in Stillwater, a northcentral Oklahoma community positioned approximately 60 miles between Tulsa and Oklahoma City. The university was founded on December 25, 1890, as Oklahoma A&M College, just 20 months after the Land Run of 1889. When the first students assembled for class, there were no buildings, no books, and no curricula. Since these humble beginnings, OSU has grown to include an 840-acre Stillwater campus and branch campuses in Tulsa, Oklahoma City, and Okmulgee, with a total enrollment just exceeding 26,000 students. The 2000 Concrete Canoe team adheres to the Oklahoma State tradition of continuing to develop and grow.

In 1999, OSU swept each of the races and all four academic categories on the way to winning its third straight regional title. The 1999 team, "The Storm," then set its hopes on a top three finish at Nationals. They placed in the top five in three of the four academic categories and racked up three top five race finishes en route to a 3rd place overall finish.

The 2000 OSU Concrete Canoe team, "Grand Slam," again swept the Mid-Continent Conference Competition, and has its eyes focused on winning a National Title.

3.0 Hull Design

3.1 Goals

The races developed by the National Concrete Canoe Committee require the hull be designed to satisfy conflicting objectives such as straight line tracking and turning maneuverability. ***Grand Slam*** is the third canoe designed by the same design team.

In 1998, the team designed a very maneuverable canoe to face the challenges of the slalom and 180° turn in the sprint. However, this design lacked the tracking and straight-line speed to be competitive at Nationals. Extensive model testing was done in 1999 to determine how tracking and straight-line speed could be increased without lengthening the canoe. A canoe with identical dimensions--19 feet long, 30 inches wide, and 10 inches deep--improved nationally from 8th to 3rd overall in the races. Despite our improvements, the OSU faithful watched the longer canoes catch and sometimes pass the faster starting and turning 1999 OSU canoe.

The primary goal for ***Grand Slam*** was more speed. However, eliminating 1999 hull design flaws and maintaining good maneuverability were also high priorities. Other considerations included coed loading, paddling efficiency, stability, and ease of construction.

3.2 Shape Optimization

The Hull Design Team utilized the power of experience and an in-depth literature review to isolate several key variables: length, width, cross-section shape, longitudinal shape, and rocker. The key to obtaining a successful design is minimizing the Total Drag Force (TDF).

$$TDF = C_1(V^n/L) + C_2(V^m*L)$$

C_1 and C_2 are canoe shape factors dependent on width, cross-sectional shape, longitudinal shape, and rocker. C_1 has units of mass and is based on wave drag. Wave drag represents the force required for a displacement hull to separate and return water around the hull. C_2, based on skin drag, has units of mass per area and is linearly tied to the wetted area of the hull. By reducing the wetted area, the skin drag can be significantly reduced.

At a constant velocity the TDF is equal to the paddler input force. Likewise, if the paddler input force and length are held constant, then the canoe with the lowest values for C_1 and C_2 will have the highest velocities.

Based on this initial condition four models were constructed and tested to determine what shapes would provide the lowest values for C_1 and C_2. Each 1/10 scale model had the same overall dimensions: 24 inches long, 3 inches wide, and 1 inch deep. More than 75 flume test runs were performed to look for trends to help in the selection of a final design. Model A was identical to the 1998 canoe; Models B, C, and D represent step-by-step changes aimed at minimizing the shape factors. A brief description of each canoe's attributes is contained in Figure 1.

Drag tests were run in a flume 20 feet long, 2.5 feet wide, and 1.5 feet deep. The drag tests were performed in still water using a "smart pulley" to measure displacement vs time.

A mass of known quantity was attached to the scale models with fishing line and suspended over the "smart pulley." When the model was released, the weight of the mass would pull the model through the water and the "smart pulley" system recorded the time, in seconds, for each .015 meters of model travel. This typically amounted to more than 200 data points for each test.

Model	Cross-sectional Shape	Longitudinal Shape	Rocker
A	Flat bottom	Full and rounded	6 inches, stern and bow
B	Flat bottom	Full and rounded	none
C	elliptical	Full and rounded	none
D	elliptical	Sleek and straight	3 inches, stern only

Figure 1 – Attributes of Full Scale Canoes

Displacement, velocity, and acceleration vs time graphs were generated for each flume test run. The four models were pulled forward and backward to determine the effect of hull asymmetry. The models were also tested with different weights (fully loaded and 90% loaded) to determine the effect of paddler weight. Plots of velocity vs time from a few representative tests are shown in Figure 2.

When tested fully loaded and pulled forward the hull with the highest final velocity was Model D with a 2% improvement over the hull with the lowest final velocity, Model A. This increase in velocity proved that the TDF could be reduced independent of the length. By replacing the flat bottom cross sections with elliptical cross sections, the surface-to-volume ratio decreased, reducing the wetted perimeter

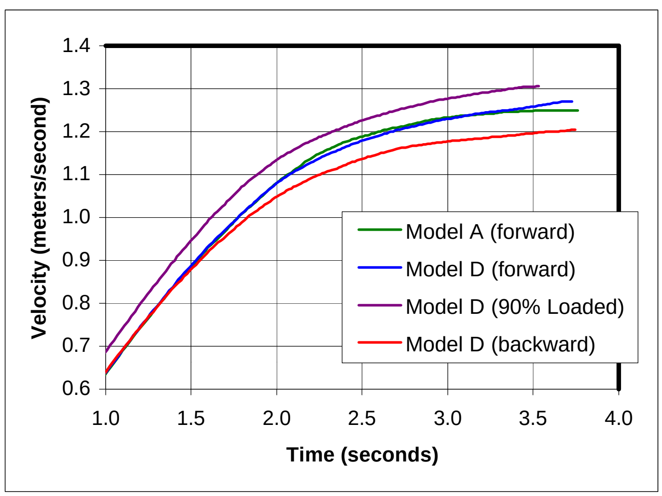

Figure 2 – Velocity vs. Time, Flume testing

and minimizing skin friction. Pulling the hulls backward clearly illustrated the effect of hull asymmetry on wave drag. By shifting the widest point of the hull 60% to the stern, the entry line became sharper and smoother, thus reducing the wave drag. When the widest point was placed only 40% from the bow (backward) it resulted in a 6% loss in final tested velocity.

The drag testing also showed that a very effective way of increasing velocity is by reducing the total weight of the canoe and paddlers. It was shown during testing that a 10% reduction in total weight resulted in a 3% increase in model velocity. While the Hull Design team realized that a 10% reduction in weight would be significant, it clearly illustrated the importance of a lightweight canoe and physically fit paddlers.

3.3 Length Considerations

The design team again analyzed the TDF equation. However, the optimal length changed with each set of paddlers. This is because each set of paddlers has a different displacement requirement, which effects C_1 and C_2, and a different input force, which is directly related to TDF.

Therefore, the design team looked at the length of the canoes that accumulated the most points in National races. The average of the top five canoes, excluding our design at 19 feet, was 21.25 feet – more than 2 feet longer than our canoe. This information, coupled with the experience of our paddling teams at Nationals, prompted the design team to increase the design length of Grand Slam to 20.5 feet. At 20.5 feet long the theoretical maximum speed of the canoe will be comparable to the design speed of the canoes that caught and passed last year's canoe.

3.4 Bow Section Testing

The 1999 OSU Concrete Canoe Team learned a valuable lesson during last year's regional and national races: "Don't assume something will work. Test it." The 1999 design team assumed a sharp deep bow section with a vertical nose would knife through the water. Unfortunately as shown in Figure 3 it acted more like a scoop.

To fix this design flaw, three full scale bow sections were designed and constructed. The sections were 3.5 feet long, 11 inches deep, and had an entry line angle of 7°.

The bow sections were tested in a constant velocity flume. The flume was 6 feet wide, 8 feet deep and 80 feet long. Approximately, 6.2 million gallons of water were siphoned from a local lake to test the bow sections. Video and still photography were used to evaluate the bow sections.

Figure 3 – Design Flaw and Flume Testing

The final bow section had a modest amount of rocker and a sharp slanted nose. Even submerged 9 inches deep, the final bow section did not take on water.

3.5 Prototype Evaluation

As a part of the mold construction discussed in section 6.0, a fiberglass practice canoe was constructed. This canoe gave potential paddlers an opportunity to test the hull design.

As projected, the increase in length made the canoe slightly more difficult to maneuver; however, when a stopwatch was used to gage the hull's performance versus the 1999 design, most paddlers realized the canoe's potential.

To date, 3 of the 5 1999 National winning times have been beaten in practice. Figure 4 displays the final design and a few of its key attributes.

4.0 Concrete Mixture Design

4.1 Target Properties

While the Hull Design team performed its analysis to optimize the hull's hydraulic performance, the Structural Design team had to respond to the demands of the four paddlers in the Coed Sprint. An Excel Spreadsheet was programmed to use imported 3-D points from AutoCAD to compute the incremental water displacements of ***Grand Slam***. The canoe weight and four paddlers were placed in the computer model and the spreadsheet computed 42 incremental buoyancy, shear, and moment forces–one for each cross section.

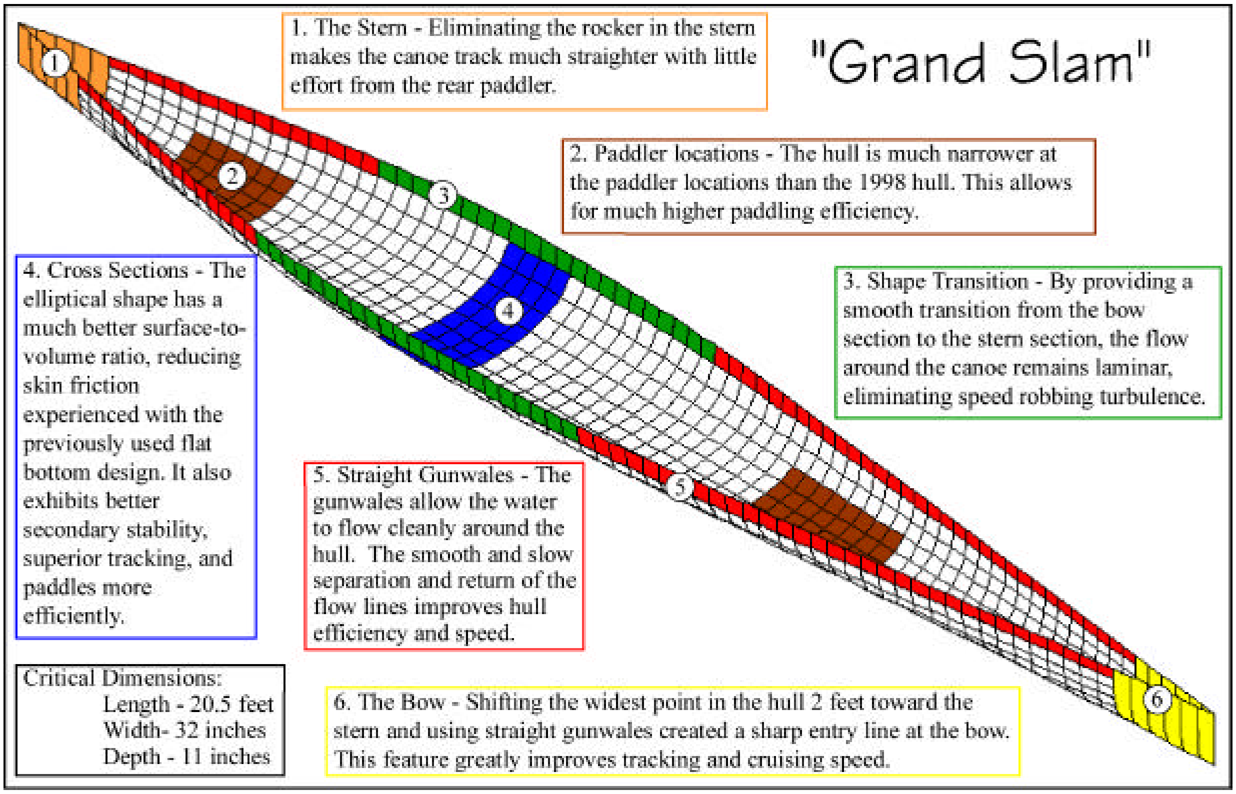

Figure 4 – Hull Design Features

As shown in Figure 5 forces generated outside the paddler locations were small and were not analyzed. However, all other cross sections were checked in shear and bending to determine necessary concrete compressive strength and tensile reinforcement strength. During the analysis two conservative assumptions were made–concrete carries no tension and reinforcement carries no compression.

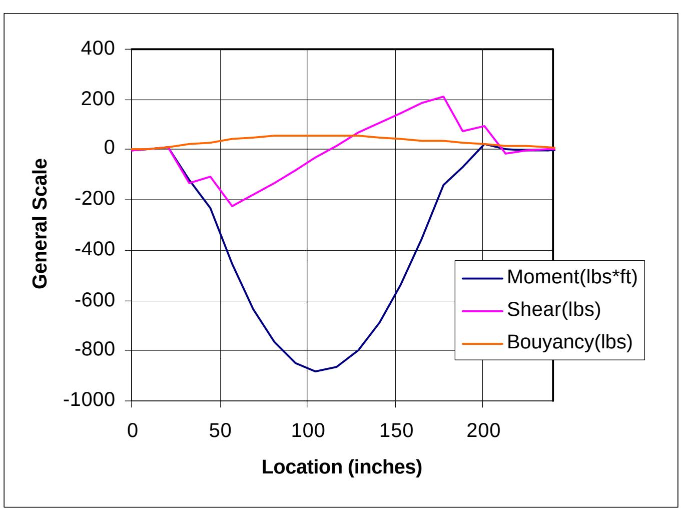

Figure 5 – Loading on Canoe Hull

The computed concrete compressive strength required was 1.9 MPa (276 psi). This was multiplied by a dynamic load factor of 2.0 and a factor of safety of 1.5 to give a final compressive strength required of 5.7 MPa (827 psi). The total tensile force required was 5.3 kN (1.19 kips).

The Excel spreadsheet also computed the total volume of concrete needed to construct a canoe 8 mm thick. When the desired weight of the canoe, 36 kg, was divided by the volume of concrete, a target concrete density of 865 kg/m^3 (54 pcf) was found.

The challenge of the unpainted section in this year's competition also prompted the design team to look at absorption and re-wetted compressive strength as design criteria as well.

4.2 Material Selection

The design team broke the material selection into three categories: binders, aggregates and random fibers, and admixtures. The search for materials and donors began on the Internet. These searches proved fruitful and informative. The design team initially settled on four binding materials, three aggregate/random fibers, and two high range water reducers (superplasticizers).

The binders selected were portland cement, silica fume, fly ash, and Laticrete® 333. The portland cement used in this year's project came directly from a cement plant without being identified; however, a chemical composition sheet was supplied. The design team checked ASTM C 150 and historical averages of portland cement types and determined our cement to be a Type I portland cement.

Silica fume and fly ash were selected for their pozzolonic properties. These pozzolons react with the products of hydration to produce additional binders. They have also been shown to reduce absorption and permeability in hardened concrete.

Laticrete® 333 is a superflexible thin set mortar latex additive that is 31% solids by weight. Latex enhances many of the desired properties of concrete canoe mixes including workability and durability, and reduces absorption and unit weight. The design team was careful to select a latex that was suitable for exterior use, since many latexes are water soluble even after curing.

The aggregates/fibers selected include Eccospheres®, Microlite-T®, and Stealth® Fibers. The Eccospheres®, also referred to as microspheres, are silica glass hollow spheres that are 100% passing a #200 sieve. The microspheres were selected as the primary aggregate used to reduce the concrete unit weight. With a true particle density of only 0.227g/cc, they produce tiny, uniform, reinforced, air voids.

Microlite-T® and Stealth® fibers added to the concrete mixtures gave them more body, making them more suitable for placement on the form. Microlite-T® is an expanded volcanic mineral with a specific gravity of 0.41. While 90% of this material still passes a #30 sieve, it is much coarser than the microspheres. Stealth® fibers are a polypropylene material that was quickly eliminated due to an inability to achieve uniform dispersion.

Reducing the water to cement ratio is an effective way to increase compressive strength, and decrease absorption and shrinkage. This prompted the design team to look at two superplasticizers: Rheobuild® 2000B and Duracem® 300M. Both had adverse reactions in the latex modified concretes; in fact, two mixtures with high dosages never cured. However, in standard mixtures w/c ratios as low as 0.30 were tested with acceptable workability.

4.3 Compression Testing

Forty-five different material combinations were tested to determine which mix constituents could be used to best meet the goals of the concrete mixture design. The wet unit weights of these mixes varied from 795 kg/m^3 (49.6 pcf) to 1362 kg/m^3 (85 pcf). The amount of cement in each trial mixture design represented 75 to 100% of the binding material, with silica fume, fly ash, and latex replacing the cement either alone or in combination.

Three to six 2-inch cubes, and one fiberglass reinforced plate were cast from each 1500 gram trial batch. The cubes were used to test unit weight, absorption, air-dry compressive strength, and re-wetted compressive strength. The plates were constructed mainly to make workability observations; however, many of the plates were tested in a pinned-pinned beam test.

Loading rates for the compression tests were done in accordance with ASTM C 39, section 7.5. A loading rate between 0.14 and 0.34 MPa/s (20 and 50 psi/s) was maintained until yielding. At yielding, no loading adjustments were made.

As specimens yielded and failed, length of yield plateau and subsequent residual strength were noted. All concrete mixtures containing latex had significantly longer yield plateaus and higher residual strengths than those mixtures without latex. Microlite-T® and polypropylene fibers also added some residual strength to non-latex concrete mixtures.

4.4 Absorption Testing

Absorption testing was done using a modified ASTM C 642. For this test a sample was weighed, oven-dried, weighed again, and placed in a water bath for 48 hours. Weights were taken after 5, 10, 20, 40, 90, 180, and 360 minutes and a final weight was taken after 48 hours.

The volume of each sample was found using a displaced water test, and unit weights were computed for each of the 8 readings.

Figure 6 shows the increase in unit weight vs time for a latex vs non-latex concrete mixture design. Both concrete mixtures had wet unit weights of about 850 kg/m^3 (53pcf) at the time of mixing.

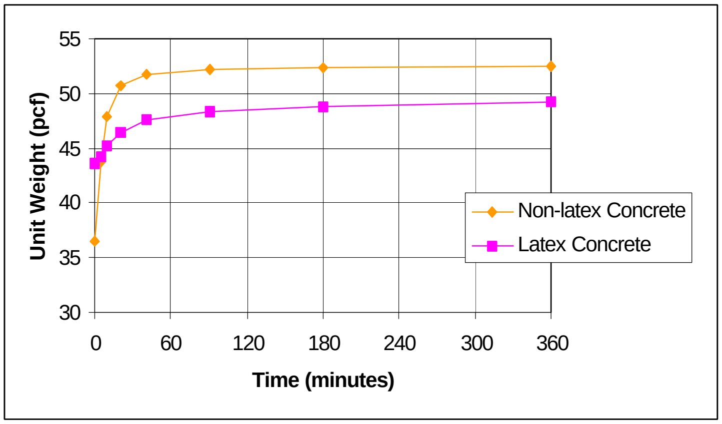

Figure 6 – Unit Weight vs. Time for Absorption

The 7-day air-dried unit weights of the non-latex and latex mixtures were 41.6 pcf and 48.1 pcf. The total change in unit weight from the oven-dry state to the saturated state for the latex and non-latex mixtures was 14.0% and 33.2%, respectively. However, the unit weight of the latex modified concrete increased only 4.2% over the air dried unit weight, while the non-latex modified concrete increased an additional 21.2% over its air-dried state.

While the unit weight of both samples climbed to within 2% of its original wet unit weight, the latex modified concrete took nearly 48 hours to reach this mark. The non-latex modified reached 98% of original wet unit weight in only 3 hours.

To test the effect of re-wetting on compressive strength, air dried samples were immersed for 24 hours. When re-wetted samples were tested in compression, there was a sharp reduction, 25-70%, in strength for the concrete mixtures with absorption percentages greater than 15%.

4.5 Final Concrete Mixture Selection

The final concrete mixture design needed to have a compressive strength greater then 5.7 MPa (827 psi), a wet unit weight less then 865 kg/m^3 (54 pcf), and an absorption percentage less than 15%.

To achieve these target properties portland cement provided the compressive strength; latex decreased the rate of absorption, percent absorption, and unit weight. Eccospheres® produced microscopic, uniform, reinforced air voids, reducing the unit weight. The addition of Microlite-T® gave the mixture body and further reduced the unit weight. Water, the universal catalyst, puts all reactions in motion. Figure 7 displays trial mixtures and the proportions for the final Patch and Grand Slam concrete mixtures.

Mix Name	1999 Mix			Non-latex Mix			Patching Mix			Grand Slam Mix		
Binding Materials	kg/m^3	pcy	%BM	kg/m^3	pcy	%BM	kg/m^3	pcy	%BM	kg/m^3	pcy	%BM
Portland Cement	427	720	75.2%	355	599	100%	375	632	81.2%	374	632	83.8%
Silica Fume	112	190	19.8%	0	0	0.0%	0	0	0.0%	0	0	0.0%
Fly Ash	28	47	5.0%	0	0	0.0%	0	0	0.0%	0	0	0.0%
Laticrete 333	0	0	0.0%	0	0	0.0%	87	147	18.8%	73	122	16.2%
Aggregates	kg/m^3	lbs./yd^3		kg/m^3	lbs./yd^3		kg/m^3	lbs./yd^3		kg/m^3	lbs./yd^3	
Eccospheres	82	139		86	145		75	126		66	111	
Microlite	45	76		20	34		0	0		42	71	
Stealth Fibers	0	0		0	0		0	0		0	0	
Admixtures												
Superplasticizer	11	19		10	17		0	0		0	0	
Water	345	581		375	633		344	580		292	493	
Properties												
7 Day Strength	11.8MPa	1712psi		7.41MPa	1075psi		7.41MPa	1075psi		6.07MPa	880psi	
Wet Unit Weight	1052kg/m^3	65.7pcf		847kg/m^3	52.9pcf		880kg/m^3	55.0pcf		847kg/m^3	52.9pcf	

Figure 7 – Trail Mixtures and Final Concrete Mixture

5.0 Reinforcement Design

5.1 Target Properties

The reinforcement design is perhaps the most difficult aspect of concrete canoe design. The Structural Design team was required to address the problems of point loads; hull rigidity; and composite durability, density, and constructability.

A concrete canoe hull is very similar to a simply supported concrete beam with a uniformly distributed load. A typical concrete beam must be designed to carry maximum moment and shear forces along its length. It also must be able to carry bearing forces associated with point loads at the supports.

An acceptable reinforced concrete canoe design must be able to carry shear and moment forces along the length of the hull in addition to redistributing bearing forces induced at paddler locations. The analysis discussed in section 4.1 generated a required tensile force along the gunwale of 5.3 kN (1.19 kips) to carry moment forces. After multiplying by a dynamic load factor of 2.0 and a safety factor of 1.5, the design tensile force required was 15.9 kN (3.57 kips).

To carry the paddler point loads the composite section was designed to bend, but not break. This is similar to holding a bed sheet on all four sides and placing a weight in its center. The bed sheet can carry no bending forces, but does resist the load by deflecting and placing the entire sheet in tension. Allowing the concrete composite section to deflect with fixed ends, rather than requiring the composite section to carry primarily bending forces, reduces the high compressive stress in the concrete and creates a higher tensile load in the reinforcement. The design team believed it was much easier to design a composite to take small bending forces and high tensile forces than develop a lightweight concrete with a compressive strength greater than 10,000 psi.

5.2 Material Selection

The design team found numerous promising reinforcements including steel hardware cloth, carbon fiber meshes, Kevlar® meshes, and fiberglass meshes. Random carbon fibers and polypropylene fibers were also considered in this phase, but were eliminated due to their high degree of unpredictability when used as a primary structural reinforcement.

All steel meshes were eliminated after reviewing the research done on steel mesh composites over the past three years at OSU. Research had shown that placing a flexible concrete mixture over a rigid steel mesh often caused spawling of concrete outside the composite and delamination between layers of steel. Lightweight concrete mixtures were not strong enough to safely pass hull stresses to the steel.

While the manufacture's data on Kevlar® were impressive, no distributor found was willing to donate enough material to test. The design team was left with two fiberglass meshes and one carbon fiber mesh.

5.3 Raw Material Testing

The first step in assessing the final reinforcement was a standard tension test to determine raw material strength. In a standard grab test, textiles typically fail at the connection with the loading apparatus. The design team elected to develop a loading apparatus that would reduce this tendency.

To reduce connection stresses reinforcement ends were rolled up on 3/4-inch diameter rollers and pinned in place. The first and last 11-inches of each 24-inch test strip were taped leaving a 2-inch test band. Failures typically occurred in the 2-inch test band. Figure 8 displays each of the materials tested, their specifications, and tested strengths.

The design team was surprised to find that the carbon fiber mesh did not perform significantly better than the fiberglass mesh. After contacting the carbon fiber mesh distributor, the design team learned that carbon fiber meshes are typically only used after pre-impregnation. The pre-impregnation bonds tiny fibers together and allows them to act as a group. Hopeful that the concrete mixture could help bond the fibers together, the design team used carbon fiber mesh in test plates despite its average performance in the raw material tests.

5.4 Pinned-Pinned Plate Testing

By using the pinned-pinned plate testing, plates were subjected to both bending and axial forces. Depending composite stiffness, the plate beneath the paddlers is subject to varying degrees of both bending and axial loads.

Sample	Direction	Tested	Data Sheet
12 x 6 sample	**12 x 6 Fiberglass**		
		Breaking Strength	
	Direction	Tested	Data Sheet
	Warp (12)	160 lbs.	140 lbs.
	Fill (6)	220 lbs.	160 lbs.
	Thickness	.0096 in	.011 in
20 x 10 sample	**20 x 10 Fiberglass**		
		Breaking Strength	
	Direction	Tested	Data Sheet
	Warp (20)	85 lbs.	95 lbs.
	Fill (10)	95 lbs.	90 lbs.
	Thickness	.0057 in	.0052 in
8X8 sample	**8 x 8 Carbon Fiber**		
		Breaking Strength	
	Direction	Tested	Data Sheet
	Warp (8)	240 lbs.	N/A
	Fill (8)	200 lbs.	N/A
	Thickness	.0126 in	N/A

Figure 8 – Samples and Raw Material Data

Figure 9 shows the load vs. deflection graph for plates constructed with each type of reinforcement and the ***Grand Slam*** concrete mixture. The graph does not show the post failure loading for Plates A and B.

Plate A, constructed with 4 layers of uniformly spaced 6 x 12 fiberglass mesh, showed modest deflection vs load. After loading the plate with 38.8 pounds, concrete on the compression side slowly crushed until the plate deflected 1.8 inches. At this point the plate could carry no bending stresses and was considered failed, but continued to take load until the test was stopped at 100 pounds of load with a final deflection of 2.0 inches.

Plate B contained 8 layers of uniformly spaced 20 x 10 fiberglass mesh. This plate had the highest deflection vs. load of the plates shown. Similar to Plate A, Plate B went through a period of high deflection at a constant load of 36.6 pounds. However, Plate B's deflection was due to a failure of 3 of the 8 layers of fiberglass mesh. Again, once the plate reached a deflection of about 1.8 inches it stopped deflecting. The test was ended at a load of 100 pounds and a deflection of 2.2 inches.

Plate C, constructed with 1 layer of carbon fiber on the compression face and one on the tension face, was relatively rigid and failed abruptly. Unlike the previous two plates, all of the reinforcement broke at a load of 41.0 pounds.

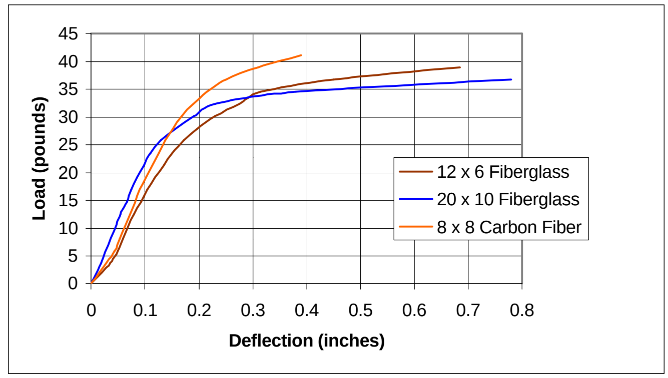

Figure 9 – Load vs. Deflection Graph

5.5 Construction Considerations

Constructability of a reinforced hull with predictable thickness was the primary focus of one series of plates. Several plates were constructed by placing alternating layers of concrete and reinforcement until a desired hull thickness of 8mm (0.31 inches) was reached.

The design team found that to achieve a reasonably repeatable thickness with the ***Grand Slam*** concrete mixture, relatively thin layers of concrete should be placed over the mesh. Using 5 layers of 12 x 6 fiberglass, 10 layers of 20 x 10 fiberglass, or 7 layers of carbon fiber mesh created a composite of uniform thickness.

5.6 Additional Structural Elements

The stiffness of a section is directly proportional to the product of the modulus of elasticity, **E**, and the moment of inertia, **I**. All of the thin reinforced composites tested had a low **EI** product and therefore low stiffness.

In order for the canoe hull to perform as it was designed–hydraulically and structurally–it must maintain its shape. To do this, hull stiffness needed to be significantly increased.

There are two ways to increase stiffness: increase **E** or increase **I**. Since **E** was already set by the concrete mixture design, the design team looked at increasing **I**. **I** for a rectangular cross section is proportional to the depth cubed. By using six 2-inch deep ribs over the widest 10 feet of the canoe, the stiffness was increased more than 25 times.

5.6 Final Reinforcement Design

After reviewing raw material data, pinned-pinned plate testing, and considering predictable constructability, the design team elected to use 10 layers of 20 x 10 fiberglass reinforcement.

One inch of 20 x 10 fiberglass reinforcement can resist a load of 95 pounds. The reinforcement design provides 10 layers of fiberglass along both gunwales. The top 1 inch of the gunwales is capable of resisting a tensile force of 8.45 kN (1.9 kips), which is more than the 5.3 kN (1.19 kips) required.

Plate testing showed that the composite was capable of distributing point loads beneath paddlers. Finally, the constructability of the composite will simplify construction and finishing.

6.0 Construction

6.1 Mold Construction

Construction of the male mold began with full-scale templates of hull cross sections. These cross sections were cut from16-gage steel sheets with a computer-driven plasma cutter at 15.2 cm (6 inches) intervals along the 6.2 m (20.5 feet) hull length.

A 6-inch block of polystyrene then was "sandwiched" between two steel templates and a special hotwire was used to cut the polystyrene along the templates. Individual polystyrene cross sections were glued together in seven larger segments. Combining individual cross sections into seven larger sections allowed for easier removal of the mold once the canoe had cured.

These segments were then placed on a specially designed table that would support the segments during casting/curing and allow removal of the mold. Included in the table and polystyrene mold was a dual keyway to ensure proper alignment of each mold segment on the table.

The Construction team was tasked with designing a mold durable enough for casting numerous canoes. To provide the required durability, the Construction team placed a fiberglass shell over the polystyrene mold.

Three layers of tightly woven fiberglass cloth were applied to the mold and coated with resin. In addition to increasing mold durability, the fiberglass layer also increased mold rigidity, which facilitated the placement of reinforcement and concrete.

6.2 Prototype Construction

The Paddling team's request for a prototype/practice canoe was met by building a fiberglass canoe from the new mold. The first step for constructing the practice canoe was applying a fiberglass release agent to the mold. Next, fiberglass mesh was cut to the approximate shape of the hull and placed on the mold. Fiberglass resin was applied to the mesh with plastic putty knives and repeated for five layers of fiberglass.

Once cured, the practice canoe was removed from the mold. To provide additional strength and rigidity to the practice canoe, 1-inch strap steel was attached along the outside of the gunwales and ¼-inch all-thread was used as thwarts. A PVC pipe was split and placed over the gunwales to prevent paddlers from getting scratched on the steel gunwales.

6.3 Ribs and Edge-Forming System

After the mold was cut into its seven sections, six 2-inch deep ribs were placed between the mold sections. The ribs were constructed from 1-inch thick plywood. Computer plots were made of each rib and then glued to the plywood. They were cut out with a jigsaw, sanded, and covered with packing tape to prevent concrete from bonding to them.

The edge-forming system consisted of a 1-inch by 3/8-inch high density plastic strip attached at the gunwale of the male mold with wood screws. This strip removed any minor longitudinal waves and created a gunwale with uniform thickness.

6.4 Concrete Canoe Construction

Prior to casting the first layer of scrim cloth, reinforcement was cut to fit the mold and then used as a pattern to cut the additional nine layers. Casting of the canoe began by filling the ribs with concrete and reinforcement, placing one layer of scrim on the mold and, applying a thin layer of concrete. The layer of concrete was placed by hand and worked in a manner so it would penetrate and slightly cover the scrim cloth. The next layer of fiberglass reinforcement was positioned on the mold and another layer of concrete was applied. This process was repeated for nine layers of fiberglass scrim cloth.

The last layer of scrim cloth was placed and a thin sanding layer of concrete was added. This produced a uniform finish without surface defects and minimized final sanding. No special curing tents were required since the latex in the mix formed a film on the outside of the concrete and locked in the water. The canoe was allowed to cure two weeks before patching and sanding were performed on the exterior of the canoe.

Once the exterior was sanded, the canoe was removed from the mold by removing each of the rib sections and removing the 7 major mold sections.

The canoe's interior received several additional hours of sanding until the desired finish was achieved. At this point the entire canoe was sealed, primed, and painted with automotive grade materials. The final coat of paint was buffed and polished to a high gloss shine. In the final step, decals and graphics were added to depict the school name and theme.

7.0 Project Management

7.1 Organizational Approach

Shortly after last year's national competition, a Project Manager was chosen for the 1999-00 concrete canoe competition. The project management began in August with the development of a basic Work Breakdown Structure (WBS).

The WBS contains all basic tasks associated with the concrete canoe design, construction, and documentation. An Organizational Breakdown Structure (OBS) was adopted, with the idea that each task in the WBS must be assigned to a committee or person.

The OBS was set up with a Project Manager, Lead Engineer, and six major committees. Each major committee had numerous task-oriented sub committees. The Project Manager scheduled, assigned, and monitored tasks, while the Lead Engineer was responsible for coordinating and reviewing the total research and design effort.

The Fundraising committee created a promotional brochure to aid in securing donations and later tracked project costs. The Hull Design committee tested new hull designs to obtain the best hull for both straight-line tracking and maneuverability. The Structural Design committee developed a concrete mix and reinforcement scheme to provide a strong, durable, final product. The Construction committee was responsible for procurement of materials, construction techniques, and display. The Academic committee provided the display content, and wrote the design paper and oral presentation. Finally, the Paddle team was responsible for quick starts, fast cruising speed, and outstanding maneuvering. While each committee had a different leader, many team members were active on several committees.

7.2 Project Implementation

Once the responsibilities were assigned, the work had to begin. To attract new students and inform incoming students, a slide presentation about the 1999 OSU Concrete Canoe Team was given at the first ASCE chapter meeting of the fall semester. The following weekend an orientation meeting was held for all people interested in being part of the team. The meeting included concrete canoe paddling for new members, a trip to the concrete canoe lab, a brief description of the 2000 OSU Concrete Canoe Team goals, and a picnic provided by the faculty.

Over the next two weeks, individuals were assigned to teams based on their interest, knowledge, and experience. Team members with the most expertise were appointed committee leaders and were asked to educate new members. Teaching was the most important responsibility of committee leaders. By passing on the knowledge of past successes and failures, team leaders guaranteed success for future canoe projects.

7.3 Project Schedule

A detailed critical path diagram was developed in August to show the interrelationships between various tasks each committee was assigned to complete. This diagram was simplified into a bar chart with specific completion dates for the major tasks.

8.0 Cost Assessment

All materials used were cataloged in a project notebook kept at the concrete canoe lab. A simple time sheet that contained spaces for name, hours spent, and specific activities performed was also kept in the project notebook. These records were periodically compiled in a spreadsheet and then removed from the project notebook.

Using the labor and material rates outlined in the 2000 Rules and Regulations, the compiled records were converted to labor and material costs detailed in the appendix. Labor costs for research/development and concrete canoe construction came to $41,979.73. Material costs for research/development and concrete canoe construction added to $3,504.02.

The grand total for development and construction of the ***Grand Slam*** was $45,384.75.

9.0 Innovative Features

The 2000 OSU Concrete Canoe project features innovations in research approach, flume testing, reinforcement design, construction techniques, and competition preparation.

One Thing at a Time – Throughout the course of the Hull, Concrete Mix, and Reinforcement Designs, the design teams used a thorough and methodical process of testing. By changing only one variable at a time, design teams could pinpoint the effect of each variable without the influence of another, ensuring that trends were identified.

"Smart Pulley" Drag Testing – One drawback with constant velocity flume testing is that all information about drag forces during acceleration is lost. Using the "smart pulley" system allowed us to look at total displacement, instantaneous velocity, and instantaneous acceleration.

Perfect Practice Makes Perfect – For the past several years the first time the paddlers experienced how the competition canoe handled was during competition at regionals. This year's team has been practicing in a perfectly shaped canoe since February. This gave the students an opportunity to become comfortable with the features of the new design over the course of 3 months, rather then 3 minutes.

Accurate Construction – The success of a design often depends on its implementation. To ensure that the mold was built to exact specifications, a dual keyway was cut into every polystyrene cross section during its production. The reinforcement scheme was chosen with construction in mind and a prototype was built to verify and refine all construction steps.

Fiberglass Scrim Reinforcement – A durable, ductile, strong, and accurate concrete composite was created. This year's composite is designed not to crack with the addition of latex modified concrete. The unit weight decreased by 10% and allowed OSU to construct its first ever inherently buoyant canoe. Additionally, the lay-up procedure resulted in a uniform thickness and reduced sanding/patching time by 200%.

Strength through Shape, Not Weight Adding material and weight is an easy way to increase strength and stiffness. However, adding a little material and weight in the right place is far superior. Two-inch deep cast-in-place ribs were implemented to provide stiffness through shape. The stiffness of the central 10 feet of the canoe was increased more than 25 times by using six ribs in that section.

10.0 Summary

The primary goal of the 2000 Oklahoma State University Concrete Canoe team was to design and construct the best canoe to ever leave Stillwater, Oklahoma. By building the longest, lightest, and fastest canoe in team history, the team has met this goal.

In 1997 OSU earned a trip to Nationals with a canoe that weighted 145 pounds. The canoe made cracking noises each time it was handled, and posted a 1:24 in the men's sprint-5 seconds slower than the best women's time.

Grand Slam weighs in at only 75 pounds and has posted times faster than 3 of the 5 1999 National winning times. Diligent research created advancements in concrete mix, reinforcement, and hull designs. A successful top down management structure ensured that the project was completed on time and under budget. Additional hours spent designing and refining construction techniques, resulted in a perfect mold for ***Grand Slam***.

The 2000 OSU Concrete Canoe Team has loaded the bases and will be looking for a ***Grand Slam*** when it steps to the plate in Golden, Colorado.