Table of Contents

EXECUTIVE SUMMARY

To: J. Bond
Location: Michigan State University; East Lansing, MI
From: M
Location: Head Quarters: London, England

Dr. Paddle has eluded the law once again and you are the only one clever enough to stop him. In order to reach his secret hideout, you must construct a concrete canoe, which will be code-named *00SPARTAN*. The canoe must be large enough to transport you and three other special agents, but light enough that two, trained agents can propel it with ease during the apprehension of this notorious villain.

00SPARTAN must weigh 218 kilograms; have a length of 6.1 meters, a maximum beam of 80 centimeters, a depth of 32 centimeters, and a thickness of 10 millimeters. Q will be delivering a new adjustable depth gage, code named Janiszewski, to guarantee uniform thickness throughout the vessel. Through the use of state-of-the-art material the concrete mix will result in a unit weight of 960 kilograms per cubic meter. The canoe shall be built with polymer reinforcing to avoid detection by the metal detectors that surround his concealed lair. *00SPARTAN* should be painted green and black to camouflage the secret concrete mix so it can move undetected through the murky waters that surround Dr. Paddle's hideout. The full design specifications are enclosed to aid you in the construction process. Good luck, J. Bond.

INTRODUCTION

Michigan State University, located in East Lansing, Michigan, was founded in 1855 as the pioneer land grant institution. It is home to over 40,000 students enrolled in 125 undergraduate programs in 14 colleges. While still a committed leader in agricultural research and instruction, MSU has also grown into a diverse educational institution.

The MSU Student Chapter of ASCE can boast of a large, active chapter membership. The chapter sponsors the Concrete Canoe Team, as well as the Steel Bridge Team, both of which perform exceptionally well in the regional and national competitions.

MSU placed first in the North Central Regional Concrete Canoe Competition in 1999. MSU has represented the North Central Region in the National Competition 10 of the last 11 years. In 1999, 1997, 1996, and 1995, MSU placed tenth, fourth, second, and third, respectively, at the National Concrete Canoe Competition.

The goal of the 2000 Michigan State University Concrete Canoe Team is to continue the school's tradition of outstanding performance. This goal can be achieved by producing the finest concrete canoe possible through the combination of valuable experience with innovative ideas.

The overall goals for this year's concrete canoe were the following:

- Reduce the mass of the canoe to increase the speed.

- Reduce the volume of the canoe to produce less drag.
- Improve the construction process.

Individual design goals were developed for the hull design, mix design, reinforcement design, and construction. Overviews of the goals are the following:

- Design a hull that is paddler-friendly
- Design a mix that is strong and lightweight
- Develop a new reinforcement scheme that eliminates steel
- Acquire a form release agent to aid in demolding
- Develop an instrument to maintain uniform thickness

HULL DESIGN

Research for the design of *00S*^PARTAN began by evaluating MSU's 1999 canoe, *High Rower*. Although *High Rower* performed well, it was obvious that *High Rower* maximum beam was much too wide at 94 centimeters. This made paddling difficult for the two mid-ship paddlers during the four-person co-ed race. Thus, this year's main objective was to design a paddler friendly hull. The configuration improves the power of the paddlers as well as providing more comfortable paddling positions.

The Department of Naval Architecture at the University of Michigan allowed the use of their facilities to perform drag testing on some of MSU's canoes. Two canoes were tested: *Absolute Spartan*, MSU's 1998 canoe, and *High Rower*. Both canoes were tested at speeds from 1.8 meters per second to 2.5 meters per second. Table 1 summarizes the results of the drag tests.

Table 1. Laboratory and Kaper Drag Comparisons

Drag Comparison Test at 2.5 m/s		
Canoe (People)	Hydrodynamics Lab (kg)	Kaper (kg)
00Spartan (2)	4.37*	3.49
00Spartan (4)	5.66*	4.22
High Rower (2)	4.60	3.63
High Rower (4)	6.09	4.45
Absolute Spartan(2)	4.43	3.54

*Estimated

Four computer programs were used to aid in the hull design of *00S*^PARTAN: Nautilus™, Kaper, I-DEAS, and MARC. Nautilus™ was used to obtain hydrostatic data and Kaper was used to estimate drag characteristics. Kaper also was used to extrapolate the hydrodynamic laboratory tests to new designs. As shown in Table 1, *00S*^PARTAN exhibits better theoretical drag results than any previous canoe. I-DEAS and MARC were used for finite element analysis and 3-D modeling.

Additional research was done on the design of Kevlar® marathon racing canoes and whitewater canoes. The marathon racing canoes have a more streamline design that creates less drag and whitewater canoes have tumblehome, which increases the structural strength of the canoe.

The team considered the following features to make the canoe paddler-friendly:

- Narrow mid-ship
- Tapered gunwales
- Volume of the bow and stern
- Tumblehome
- Rocker
- Shear line

Narrow mid-ship. The performance of a racing canoe is dependent on the streamline. A more narrow canoe produces less drag. To make the canoe narrower, the maximum beam was set at 80 centimeters. This will improve the paddling efficiency of the mid-ship paddlers during the four-person co-ed race. In order to maintain sufficient volume as well as stability, the maximum beam of 80 centimeters was kept for an approximate length of 1.5 meters [1].

Tapered gunwales. An innovative feature in the design of *00SPARTAN* was the integration of tapered gunwales. The gunwales were tapered inward beginning one meter abaft mid-ship to improve the efficiency of the stern paddler. Thus, when the stern paddler reaches forward to initiate a stroke, the gunwales will not interfere with the stroke and the paddler will have more leverage. The tapered design reduced the volume of the canoe, which is undesirable for the four-person co-ed race; therefore more volume was needed in other sections of the canoe.

Volume of the bow and stern. Moving the 1.5-meter section of 80-centimeter width towards to the front of the canoe increased the volume of the bow. To funnel the increased bow volume, the entry angle of the canoe was set at 23 degrees. The wide entry angle will allow the bow paddler to sit forward more comfortably and allow a greater mechanical advantage during turning maneuvers. In order to compensate for the additional bow volume, the volume in the stern had to be increased without affecting the tapered gunwales. Thus, the volume was increased behind the tapered gunwale section to insure an even keel. The increase in stern volume reduces the potential for submerging the stern at the end of a paddle stroke. The added buoyancy to the stern section will also help overcome the canoe's tendency to climb its own bow wave.

Tumblehome. Tumblehome was added to the cross-section of the canoe at mid-ship, similar to a whitewater canoe, to increase structural strength. Although tumblehome slightly reduces the final stability, it allows the mid-ship paddlers to paddle more efficiently. Tumblehome allows the mid-ship paddler to more easily reach over the sides of the canoe.

Rocker. Evidence from last year's canoe proved that a large amount of rocker made buoy turns easier during the slalom races, but made the canoe more difficult to handle on straight courses. To increase tracking the front edge of the bow was sharpened and the total rocker was reduced from 152 millimeters to 140 millimeters. The underside of the stern section was then rounded to insure minimal lateral resistance during buoy turning.

Shear line. The bow gunwales contain the greatest shear line and flare, which provides extra freeboard. Extra freeboard decreases the amount of water intake during the four-person co-ed race. Conversely, the shear line in the stern was decreased. This was done to decrease the weight of the canoe and to produce a sleek profile, which will be less susceptible to problems created by a side wind. The most significant characteristics of *00S*PARTAN's hull design are illustrated in Figure 1.

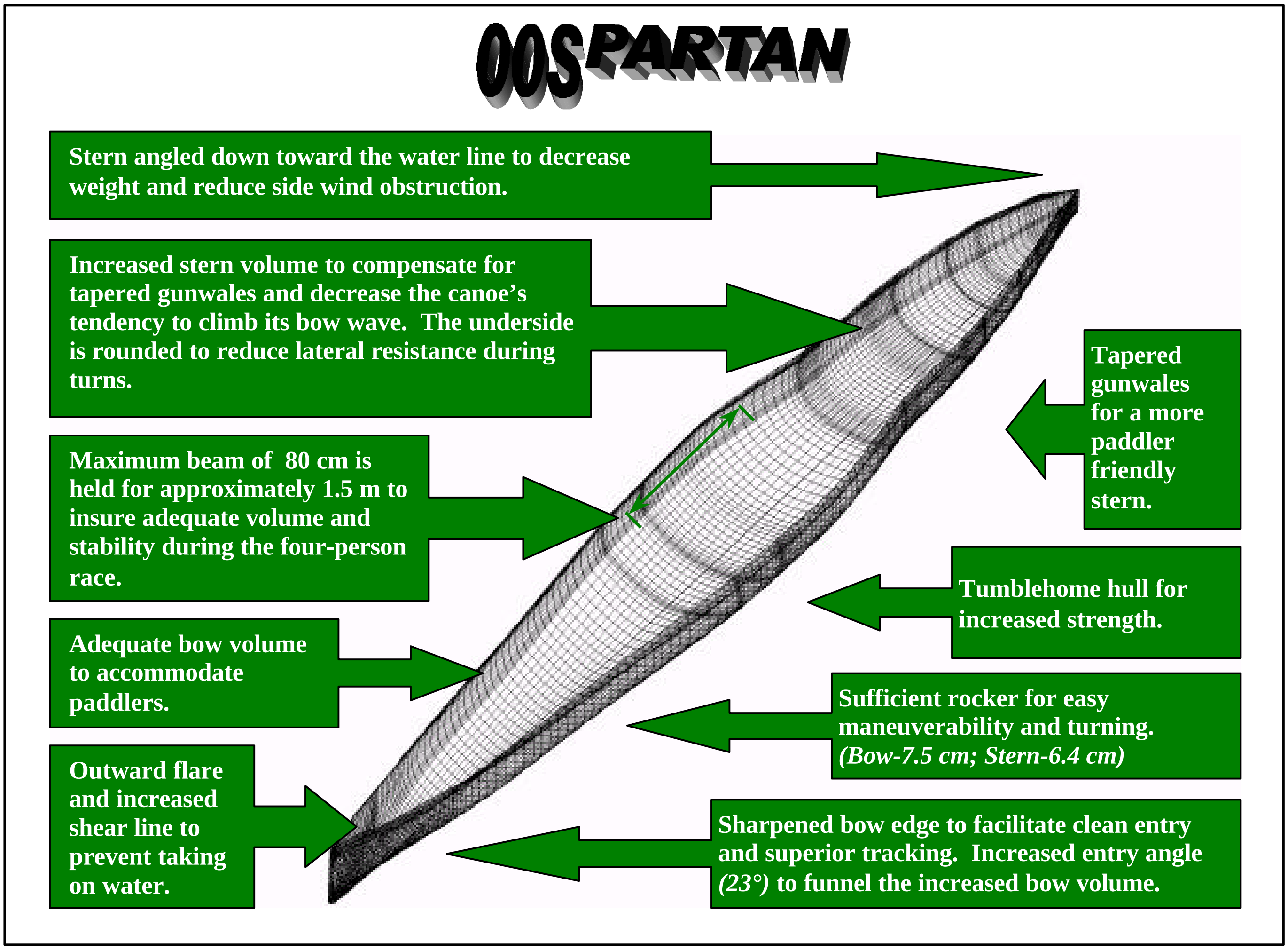

Figure 1. *00S*PARTAN 's streamline, paddler-friendly, and robust hull design

CONCRETE MIX DESIGN

The initial goals for the concrete mix design were the following:

- Optimize aggregate mix
- Maximize strength
- Minimize unit weight

Aggregate mix. The team wanted to find two lightweight aggregates that would improve workability and finishability of the mix. Three different aggregates were tested, Microlite T (Big T), Microlite XT (Little XT), and Extendospheres (Tend X). Both Big T and Tend X were selected for the final mix.

Big T and Little XT have very similar properties. One important feature of Big T is its hydrophobic coating, which prevents any water from being absorbed. The hydrophobic coating has an absorption capacity of 0%. Little XT does not have a hydrophobic coating and as a result, has an absorption capacity of 300% of its weight; therefore it was not used in the final mix [2]. The high absorption capacity of the aggregate requires more water to insure full hydration of the cement. The result of adding more water to the concrete is an increase in unit weight.

Little XT was tested based on the speculation that it would increase the compressive strength of the concrete [3]. The speculation was made because it was assumed that a stronger bond would form with the cement paste due to the absence of a hydrophobic coating. According to the test results displayed in Table 2, no compressive strength will be gained from using Little XT. Little XT also increased the unit weight of the mix by an average of 137 kilograms per cubic meter, which is an undesirable result.

Big T was selected for the final mix because it adds little weight to the mix, does not compromise the compressive strength, and reduces shrinkage cracks [2]. Due to Big T's 0% absorption capacity less water is required for the mix.

The specific gravity of Big T could not be determined accurately using ASTM C 128-93 because the aggregate is lightweight and absorbs no water [4]. The manufacturer's procedure for determining specific gravity is outlined in the Technical Appendix. The manufacturer's value for specific gravity (G_s=0.41) was used for all calculations.

Tend X was used in the final mix because it resulted in a superior compressive strength of the mix. Tend X has a specific gravity of 0.72 and an absorption capacity of 32%. The specific gravity and absorption capacity were determined in accordance with ASTM C 128-93.

Strength and unit weight. The optimal mix design was selected from 36 preliminary mixes. Each mix was tested by making three test cylinders per mix according to ASTM C 31, and was tested for compressive strength and unit weight according to ASTM C 39-94 [5,6]. The tests are summarized in Table 2. The mixes in Table 2 were varied by percent aggregate, type of aggregate, and water to binder ratio.

Table 2. Concrete Trial Mixes

MIX ID	Mix Proportions												Mix Properties			
	Other				Binding Materials				Aggregates				28 Day		28 Day	
	Water		Fiber		Cement (75%)		Latex (25%)		Microlite		Extendospheres		f'c		Unit Weight	
	kg/m^3	(lb/yd^3)	kg/m^3	(lb/yd^3)	kg/m^3	(lb/yd^3)	kg/m^3	(lb/yd^3)	kg/m^3	(lb/yd^3)	kg/m^3	(lb/yd^3)	kPa	(lb/in^2)	kg/m^3	(lb/ft^3)
OO1	221.7	(373.7)	0.0	(0.0)	504.3	(850.0)	117.9	(198.8)	299.8	(505.4)	140.0	(235.9)	5184.9	(752.0)	929.0	(58.0)
OO2	113.4	(191.2)	0.0	(0.0)	379.0	(638.9)	266.0	(448.3)	249.9	(421.2)	174.9	(294.8)	2187.7	(317.3)	828.1	(51.7)
OO3	82.9	(139.8)	0.0	(0.0)	341.7	(576.0)	308.3	(519.7)	299.8	(505.4)	140.0	(235.9)	3797.0	(550.7)	852.2	(53.2)
OO4	113.4	(191.2)	0.0	(0.0)	379.0	(638.9)	266.0	(448.3)	149.9	(252.7)	244.9	(412.8)	1149.4	(166.7)	885.8	(55.3)
OO5	113.4	(191.2)	0.0	(0.0)	379.0	(638.9)	266.0	(448.3)	100.0	(168.5)	279.8	(471.7)	524.0	(76.0)	949.9	(59.3)
OO6	7.5	(12.6)	0.0	(0.0)	358.9	(605.0)	251.8	(424.5)	83.9	(141.5)	314.8	(530.7)	4707.1	(682.7)	962.7	(60.1)
OO7	9.0	(15.1)	3.0	(5.0)	358.9	(605.0)	251.8	(424.5)	62.9	(106.1)	349.8	(589.7)	5364.2	(778.0)	772.1	(48.2)
00S^PARTAN	5.2	(8.7)	3.0	(5.0)	360.7	(608.0)	253.1	(426.7)	41.9	(70.7)	372.2	(627.4)	7929.0	(1150.0)	849.0	(53.0)
OO8	4.3	(7.2)	3.0	(5.0)	358.9	(605.0)	251.8	(424.5)	41.9	(70.7)	384.8	(648.7)	5460.7	(792.0)	770.5	(48.1)
OO9	3.2	(5.4)	0.0	(0.0)	358.9	(605.0)	251.8	(424.5)	21.0	(35.4)	419.8	(707.6)	5240.0	(760.0)	799.3	(49.9)
OO10	113.1	(190.7)	0.0	(0.0)	379.3	(639.4)	266.2	(448.7)	184.4	(310.8)	35.0	(59.0)	262.0	(38.0)	988.3	(61.7)
OO11	191.1	(322.2)	0.0	(0.0)	302.7	(510.3)	212.4	(358.1)	143.5	(241.8)	104.9	(176.9)	1875.4	(272.0)	977.1	(61.0)
OO12	191.1	(322.2)	0.0	(0.0)	302.7	(510.3)	212.4	(358.1)	163.9	(276.3)	69.9	(117.9)	372.3	(54.0)	994.7	(62.1)
OO13	113.1	(190.7)	0.0	(0.0)	379.3	(639.4)	266.2	(448.7)	122.9	(207.2)	140.0	(235.9)	289.6	(42.0)	903.4	(56.4)

Overall, the results from the preliminary mixes showed that an increase in aggregate content resulted in a decrease in unit weight. This can be explained by the fact that the aggregates are the lightest component of the mixture. In addition, an increase in aggregate content also resulted in a decrease of compressive strength. The use of two different sized lightweight aggregates actually compensated for the decrease in strength while reducing the unit weight. Compressive strength was gained two ways. One way was because Tend X has a high compressive strength. The second way was because when the pores between the aggregates of a larger size are filled with aggregates of a smaller size, a stronger bond is formed between the aggregates and the cement paste.

The team selected liquid latex as an admixture for the mix design because it improves the compressive strength of the concrete as well as reducing the unit weight of the mix. Latex also improves the workability of the mix by acting as a super-plasticizer.

The final mix design that was selected for $00S^{PARTAN}$ is shown below in Table 3, has a unit weight of 849 kilograms per cubic meter, and a 28-day average compressive strength of 1150 kilopascals.

Table 3. Final Mix Design

MIX ID	Mix Proportions												Mix Properties			
	Other				Binding Materials				Aggregates				28 Day		28 Day	
	Water		Fiber		Cement (75%)		Latex (25%)		Microlite		Extendospheres		f'c		Unit Weight	
	kg/m^3	(lb/yd^3)	kg/m^3	(lb/yd^3)	kg/m^3	(lb/yd^3)	kg/m^3	(lb/yd^3)	kg/m^3	(lb/yd^3)	kg/m^3	(lb/yd^3)	kPa	(lb/in^2)	kg/m^3	(lb/ft^3)
$00S^{PARTAN}$	5.2	(8.7)	3.0	(5.0)	360.7	(608.0)	253.1	(426.7)	41.9	(70.7)	372.2	(627.4)	7929.0	(1150.0)	849.0	(53.0)

REINFORCEMENT DESIGN

The goals set for the reinforcement were:

- Replace steel as the primary reinforcement
- Maintain design strengths of previous years
- Incorporate finite element analysis (FEA) in material selection
- Maintain ease of application
- Reduce weight

Table 4. Volumetric Comparison to Determine Weight Saved

Composite Section	Weight Saved (lbs)	
	Steel vs Fiber 1	Steel vs Fiber 2
1 Ply 1/2" Steel	5.55	3.74
2 Ply 1/2" and 1/4" Steel	6.74	4.71

Replacement of steel. The change from traditional steel reinforcement to the fiberglass reinforcement chosen this year was a major innovation for the 1999-2000 team. MSU's previous teams used steel as the primary reinforcing material. Preliminary analysis was done in order to determine the necessity of changing materials. A volumetric algorithm was used to determine the amount of weight that could be saved. The results are summarized in Table 4. "Weight saved" in Table 4 is based on the 1998-1999 Canoe *High Rower*. Fiber 1 represents high strength carbon fiber and has an elastic modulus of 2.0E8 kilopascals. Fiber 2 represents E-glass fiber and has an elastic modulus of 7.6E7 kilopascals. Fibers 1 and 2 were chosen to represent the upper and lower range of materials possible. From the data in Table 1, the team decided that changing the reinforcing material would be beneficial in reducing the weight for $00S^{PARTAN}$.

FEA. Using I-DEAS and MARC software a finite element analysis (FEA) was performed to determine the necessary strength of the reinforcement [7,8]. Material data from this year's mix was incorporated into the analysis. Models created from the design team were analyzed with un-reinforced concrete to determine minimum required strengths of the reinforcing materials.

I-DEAS was the primary FEA program used for analysis and MARC was used as a check. The analysis was done for two possible cases, self-weight of the canoe (transportation) and carrying four paddlers. Based on previous years' analysis these two cases proved to be the worst. In order to model the self-weight of the canoe, the canoe was treated as a simply supported beam. The paddlers were modeled as four 80-kilogram point loads. Final analysis showed that carrying four paddlers produced the worst tensile stresses along the bottom of the canoe. Figure 2 shows the maximum tensile stress to be 2170 kilopascals located in the red regions. Maximum tensile stress due to carrying was 580 kilopascals. The data was verified using the MARC program.

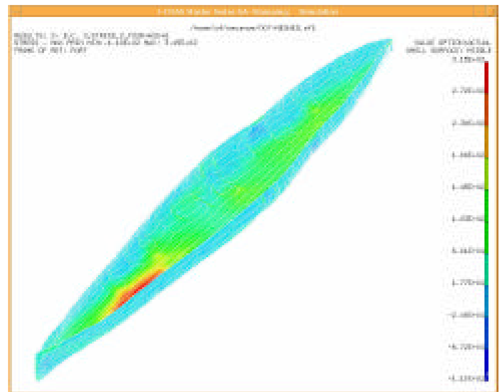

Figure 2. I-DEAS modeling

Table 5. Tensile Properties

	Yield Strength Mpa	(psi)
1/4" Steel 23 Ga.	410	59500
1/2" Steel 20 Ga.	403	58500
Intermdiate® Mesh	948	137500
Fibacrete® XS-Extra Standard	1077	156250
Glass Grid	513	74419
Polypropylene	103	15000

The materials selected for testing included: carbon mesh, fiberglass mesh, Kevlar®, polypropylene, and steel mesh. Two sets of test samples were made. Raw material samples and concrete composite samples. Raw material samples were cut and tested using a modified ASTM A 370 test to determine the material's tensile strength [9]. The results were inconsistent and unreliable so values were obtained using manufacturer's technical data sheets and are displayed in Table 5. The high yield strength of the GlasGrid, Fibacrete®, and Intermediate® were chosen because concrete has little capacity to resist tensile loading and the worst stresses in 00SPARTAN's hull were tensile. Secondly the yield strengths of the chosen material were much higher than steel. Concrete composite specimens were cast to simulate the shell of the canoe. A total of thirty-two 152 x 305 x 10-millimeter specimens composed of concrete and reinforcement were made. Several different layer combinations were tested to determine the best flexure strength with the least weight. The concrete composite specimens were tested according to ASTM C293-94 to determine the flexural strength of each specimen [10]. Samples containing Carbon and Kevlar® gave the best results; however they did not conform to rule II.C.8 in the 1999-2000

Table 6. Concrete Composite Material Summary

Specimen	Max Stess (MPa)	(psi)	Weight (g)	(lb)
2 Ply 1/4" Steel, 1/2" Steel	10.22	1482.56	443.90	0.9788
2 Ply GlasGrid, Fibacrete®	5.65	819.71	360.00	0.7938
2 Ply GlasGrid, Intermediate® Mesh	5.64	817.99	369.60	0.8150
3 Ply GlasGrid, Intermediate® Mesh, Fibacrete®	9.93	1439.66	414.20	0.9133
2 Ply 1/2" Steel, Polypropylene	5.15	747.07	349.00	0.7695
Control	1.85	268.67	310.60	0.6849

NCCC rules and regulations, thus they were discarded. Table 6 summarizes the viable choices. FEA analysis showed that the maximum stress requirement was 580 kilopascals for self-weight of the canoe. The 2-ply composite of the black GlasGrid and Intermediate® Mesh will resist 5630 kilopascals resulting in a factor of safety of 9.7. The maximum stress area produced under the paddlers was 2170 kilopascals so the third layer of Fibacrete® was added to achieve a factor of safety of 4.5.

Ease of application. Finally ease of placement and thickness parameters were considered. Application of reinforcing materials had to be quick and accurate due to the construction methods used. In order to accommodate the construction process GlasGrid, Intermediate® Mesh®, and Fibacrete® were chosen based on their performance during preliminary tests. While making the concrete composite test specimens the three materials mentioned above, layered the best. Which means, when placed on the concrete layer they did not bend or move to the surface as the steel did. No additional tie downs were necessary, which would have slowed construction and compromised the mold release process. Thickness of the reinforcement was measured according to rule II.C.8 and the results are displayed in the Technical Appendix. The reinforcement accounts for 20.8% of the total thickness of the canoe, well below the allowance stated in rule II.C.8.

CONSTRUCTION

The construction phase emphasized three objectives:

- Maintain uniform thickness
- Improve the mold release process
- Reduce sanding time by improving the mold finish

Forming the mold. The success of previous years' molds led the Construction Team to use similar methods in forming a male mold. Expanded Polystyrene (ESP) foam with regrind was used to form the male mold. This year, the foam was cut into smaller sections to provide definition at sharp dimensional changes of the canoe. Cross-sections of widths 8, 15, and 30-centimeters were used.

The cross-sections were printed through the Nautalis® program at established stations that matched the different sizes of ESP sections. The printed cross-sections were glued to masonite board and cut out with a jig saw. The cut masonite board was then attached to the appropriate ESP foam section with screws. A custom-built hot wire was used to cut the ESP foam, using the masonite as a guide. The sections were then glued together and attached to the construction table. The foam was sanded to eliminate any imperfections caused by the hot wire. Plastic screen trim was affixed to the ESP foam at the bottom edge of the canoe mold to provide smooth lines along the gunwales when the concrete was applied. Drywall compound, with a 20 minute set time, was applied and sanded three times to provide a smooth and level surface. The drywall compound was then covered with a primer to prevent the drywall compound from absorbing the release agent.

Based on a construction management analysis of the critical time requirement in placing concrete, three crews were formed: concrete mixers, concrete appliers, and reinforcement placers. Prior to casting day, the three layers of reinforcement were precut, providing a perfect fit on the concrete.

On the day of casting the mixing of the concrete was done by hand to maintain the integrity of the Tend X. If Tend X is exposed to a large amount of pressure, which may be generated with a mixing devise, the hollow ceramic spheres collapse.

Concrete placement. Time was an issue in placing the concrete because it had to be applied prior to the initial set time. The cast was scheduled to be completely finished within one hour of the water and cement mixing together. This is done in order to give the concrete as much strength as possible before the hydration process begins, further movement of the concrete breaks the initial bonds formed by the cement and the water.

Reinforcement placement. After the initial layer of concrete was applied, the reinforcement was placed over the concrete. The concrete appliers then worked the reinforcement down into the initial layer of concrete by hand and by vibration before placing a final layer of concrete over the reinforcement. During the entire cast, one team member ensured the appropriate thickness was maintained throughout each layer with the Janiszewski. The result is a final overall thickness of 10 millimeters. The adjustable depth gage was custom built using a steel plate with three adjustable pins.

Curing. Once the concrete was finished and the curing process began, soaked burlap sacks were placed on the canoe mold. Humidifiers were also placed under the mold to keep a consistent amount of moisture on the concrete to prevent the concrete from drying out. A constant temperature was set at approximately 18°C.

00S^PARTAN was allowed to wet cure for four days and then the burlap sacks and humidifiers were removed to allow for 25 days of dry curing. Following eleven days of curing, the exterior of *00S^PARTAN* was sanded with hand held vibrating sanders. Sanding was performed in a softly lighted area to identify any blemishes.

Demolding. The following release agents were tested on sample cross-sections: two waxes, Maguire's Maximum Mold Release® and Johnson's Paste Wax®, and an aerosol spray, Crete-Lease 20 VOC®. The results of the sample cross-section showed that the sample with the Crete-Lease 20 VOC® was extremely easy to demold and left behind a smooth finish on the concrete. Therefore, it was used as the release agent.

The canoe was removed from the male mold and the interior was sanded. In order to ensure the thickness at the gunwales was maintained at 10 millimeters, a tool was designed to scribe a line along the gunwales. The line let the sanders know when the gunwales were the appropriate thickness. After the sanders achieved a smooth finish, the canoe was primed and painted.

PROJECT MANAGEMENT

Teams Organizational Structure

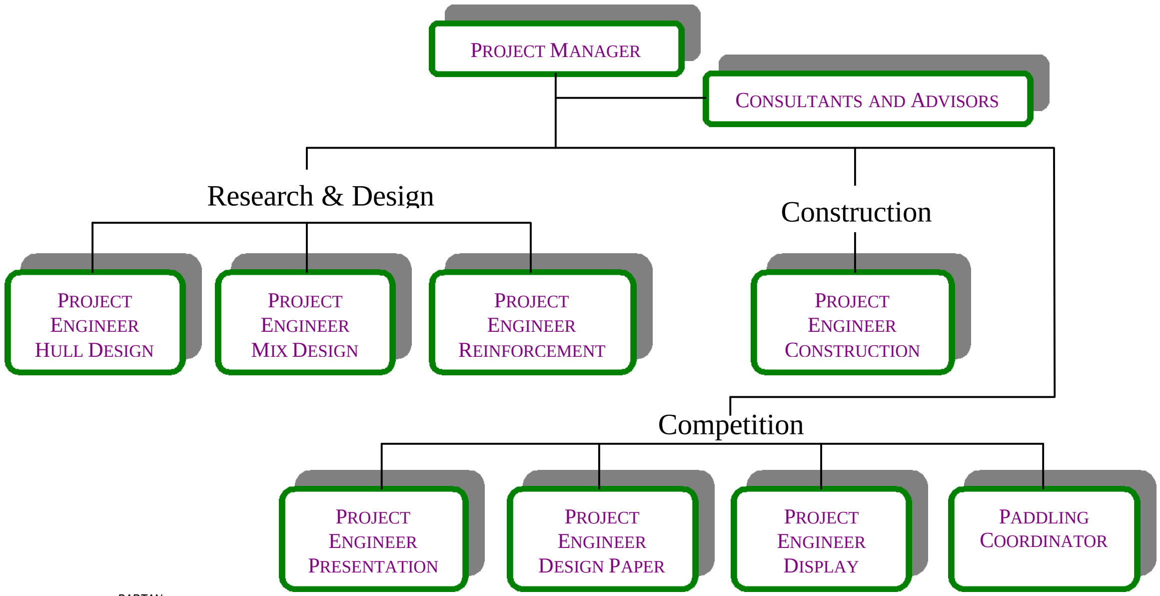

Figure 3: *00S*[PARTAN]'s Organizational Structure

Past years' experience has shown which project management methods utilize time and money most efficiently. Last year's team discovered that it was unnecessary to have weekly meetings for the whole team, instead they decided to have a weekly meeting for project engineers. The project engineers were responsible for setting goals and scheduling work time for their respective committees to meet. This is the format that was used for this year's team. Figure 3 above illustrates the team's organizational structure.

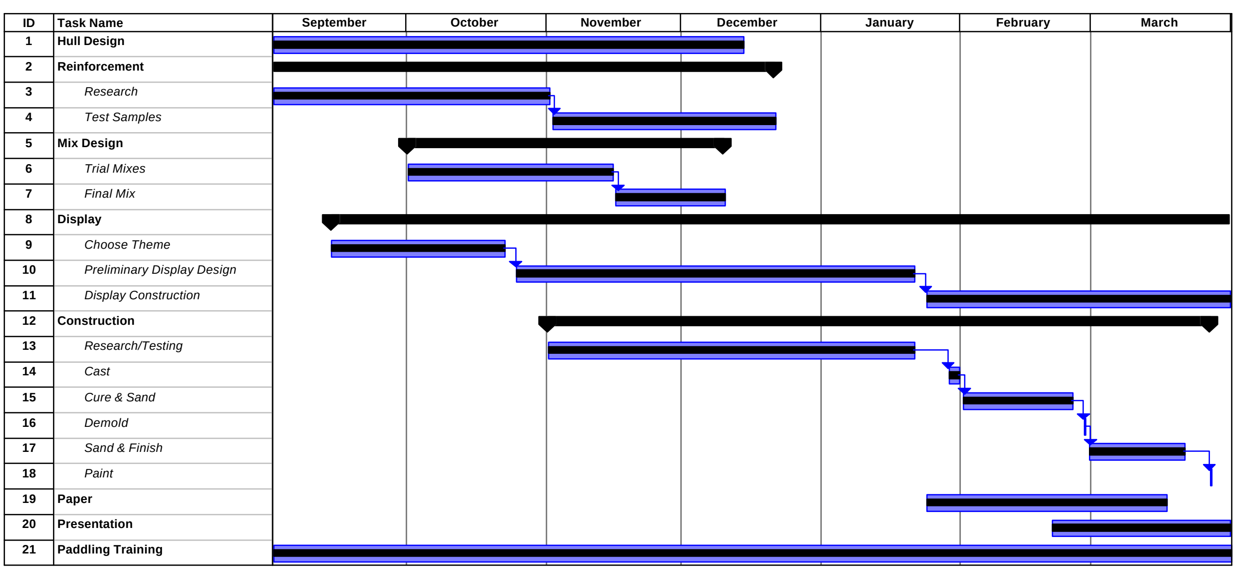

Figure 4. Timeline of *00S*[PARTAN]'s Creation

The project manager set a schedule at the beginning of the year to outline the time frames in which all committee activities should take place. The schedule was put into Microsoft Project® [11] and can be found above in Figure 4.

The meetings that were held weekly involved the project manager and project engineers. The project engineers reported on the progress of their committees, and times were scheduled for workdays for the entire team. Typical workdays included mass mix, fundraising, mold construction, casting, and display construction.

COST ASSESSMENT

The cost data, located in Appendix A-1, displays a detailed assessment for the project. A total of 1048 hours of labor resulted in a direct billable labor cost of $51,389.99, which incorporates the required Direct and Indirect Employee Costs (DEC and IEC) of 1.4 and 1.25 respectively, and a profit margin of 15%. The materials used to build the mold, practice canoe, and 00Spartan cost $6,185.81. Consulting costs of $10,000.00 and a 10% markup produced a total expense of $17,804.39. The grand total cost for this project was $69,194.38.

INNOVATIVE FEATURES

The opportunity to represent the North Central Region at the 1999 National Concrete Canoe Competition lead the 2000 team to the many innovative features utilized this year. These innovations helped create the paddler-friendly, streamline canoe: $00S^{PARTAN}$. The innovations of $00S^{PARTAN}$, which adhere to the 2000 National Rules and Regulations, are summarized below.

- Radical change in hull design
- Selection of optimal aggregate proportions
- New reinforcement design
- Volumetric comparison of reinforcement
- Determination of effective modulus properties of reinforcement
- Prediction of new composite weights
- Elimination of tie downs and spacers for reinforcement placement
- Selection of new release agent
- Construction of smaller mold cross sections
- Placement of wood strip along edge of mold for gunwales
- Design and construction of adjustable depth gage
- Design and construction of gunwale scribe
- Construction of a fiber glass training canoe

SUMMARY

$00S^{PARTAN}$ has a hydrodynamically efficient, paddler-friendly hull design. Based on extensive research, the fabrication materials include aggregate and reinforcing that minimize weight and maximize strength at critical points. Innovative design and construction features, as well as efficient organization and management, have resulted in a state-of-the-art concrete canoe that will accomplish its mission.