1.0 Introduction/Executive Summary

The University of Wisconsin-Madison is located in the heart of Madison, Wisconsin. It is situated only a short distance from the State Capitol, and proudly rests on the isthmus created by the adjacent lakes Mendota and Monona. Founded in 1848, the UW-Madison consists of more than 40,000 students, with over 300 pursuing a degree in Civil and Environmental Engineering. Among these students, nearly forty spent their time and efforts on this year's canoe: *Mine Bender*.

As it is widely known, the Badger is the UW-Madison mascot. What is not as widely known is that this name does not come from an abundance of badgers in the state, but rather from the zinc and lead miners who helped settle the state. As winters approached, miners migrated south to avoid the harsh cold. Remaining miners that braved the Wisconsin winters typically burrowed themselves into personal dugouts as a way of staying out of the elements. These men were given the nickname "badgers" due to their resemblance to the burrowing animal found in the area.

The UW-Madison is proud to enter *Mine Bender* in the 2002 National Concrete Canoe Competition (NCCC) as the Great Lakes Regional Competition winner. Past successes in this conference have allowed our teams to experience the NCCC since 1995—with a top finish of 7^{th} place in the 2000 contest. Last year, *Eclipse* finished 11^{th} overall, aided by an impressive 6^{th} place finish in the races.

Building upon last year's canoe, we feel that *Mine Bender* will once again place the UW-Madison among the top at the NCCC. A summary of *Mine Bender*'s dimensions is found in Table 1. This year's team has greatly increased the strength of the concrete mix while maintaining its weight, improved accuracy involved with mold construction, and introduced a modified flare into the hull design. Additionally, to improve paddler performance, two practice canoes were constructed from the actual mold. In previous years only one practice canoe was cast.

Table 1: Canoe Dimensions

Mine Bender **- The Facts:**	
Weight:	556 N (125 lbf)
Length:	6.1 m (20 ft)
Beam:	737 mm (29 in.)
Depth (at beam):	356 mm (14 in.)
Thickness (unfinished):	9.5 mm (0.375 in.)
Colors:	Orange, Yellow, Unpainted

2.0 Hull Design

The performance of any canoe is based on its ability to efficiently displace and replace the water as the canoe is propelled forward. The *Mine Bender* hull design team is led by a group of skilled paddlers, creating a design that integrates on-the-water experience with theory. With a 6^{th} place overall finish in the 2001 NCCC races, the team was pleased with the performance of *Eclipse*. *Mine Bender*'s hull is therefore based on a confirmed design while improving on its shortcomings. ProSurf version 2.1 is the software program that has proven to suit our needs in the analysis and design of the hull.

Eclipse was a very fast canoe, but it lacked dynamic stability under way and secondary stability when heeled to facilitate turning. To improve the overall stability, this year's design team decided to maintain the sharp-V cross-section of *Eclipse* in the bow and stern while creating a center section with a more rounded-V. Figure 1 displays bow and stern sections in 305 mm (1 ft) increments.

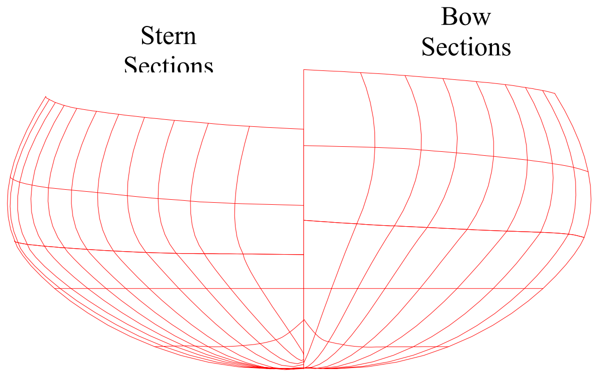

Figure 1: Section View of *Mine Bender*

A rounded cross-section provides more lateral stability, minimizing the energy lost from the unnecessary movement and giving paddlers more confidence in applying power, especially in the slalom course.

Eclipse was effective with its narrow beam at the waterline and sharp-V entry. It utilized an efficient exit line for minimizing tail wake, thus minimizing the drag by reducing the pressure difference between the bow and stern.[1] To keep this efficiency, the design team modified only the bow so that *Mine Bender* would become more seaworthy but still maintain a narrow entry. This was accomplished by incorporating a modified flare in the bow above the waterline. The sharp-V is maintained, and additional seaworthiness is achieved by exaggerating the beam out to two times the width at the waterline. This shape prevents the boat from reacting to small waves and wind chop, and allows the bow to rise over larger waves and swells.

Excellent performance is achieved not only by a proper shape, but also by the movement of the paddle into, through, and out of the water. Tumblehome brings in the beam to a width of 635 mm (25 in.) at the top of the hull so that the paddlers can comfortably place the blade in the water for an efficient stroke. Although the overall beam from last year increased from 660 mm (26 in.) to 737 mm (29 in.), the paddlers can still reach from side to side without damaging the canoe.

Our paddlers have trained many hours to prepare for the challenge of competition. We believe that *Mine Bender*'s advanced design will allow them to succeed.

3.0 Structural Design

3.1 Concrete Mixture Design

Evidence from last year's NCCC proved that heavier does not necessarily mean slower. *Eclipse* pushed the limits of lightweight concrete strength, which resulted in hull damage beneath paddlers and at the gunwales. One goal of this year's team was to increase the strength of the concrete to eliminate these problems. Another goal was to minimize skin friction drag by maintaining the finishing qualities of *Eclipse*; these objectives were achieved through aggregate selection.

Aggregates contribute to overall strength and weight, while also playing a major role in the finish of the canoe. Based on twenty-six mix designs, we chose to work with ceramic beads and glass bubbles. These lightweight aggregates were tested in various proportions to achieve the 5.5 MPa (800 psi) desired strength.

In addition to aggregates, other components were also considered. Type III Portland cement was chosen for its ability to gain high early strength.[2] This characteristic allowed the team to work on the finish of the canoe shortly after it was removed from the mold. Fly ash was used to aid workability. The spherical shape of fly ash allows the particles to roll over each other, thus increasing the workability of the mix.[3] Microsilica was the final binder used due to its fine, spherical shape allowing for a denser and stronger concrete. In addition to its physical characteristics, its chemical properties also increase concrete strength. Microsilica results in both a stronger paste and an improved paste-aggregate interface.[4] Utilizing microsilica in the mix creates a higher strength concrete without adding significantly to the weight. In comparing the pour mix (5.6 MPa compression strength) to the selected test mix (4.1 MPa), we found that a higher percentage of microsilica increased overall strength.

In testing, four cylinders of each of the twenty-six mix designs were cast according to ASTM C 129. Cylinders were tested at 7 and 28 days following the ASTM C 39 standard. Table 2 compares the pour mix proportions for *Mine Bender* and *Eclipse*.

Once the desired strength was achieved in our mixes, the mix with the highest strength to weight ratio was chosen. We were able to accomplish our mix design goal by increasing the strength 2.1 MPa (300 psi) while only increasing the unit weight 48 kg/m^3 (3 lb/ft^3).

Table 2: Pour Mix Comparison

	Mine Bender	**Eclipse**
Binding Materials	kg/m^3 (lb/ft^3) [%]	
Portland Cement	216.8 (13.5) [83]	207.1 (12.9) [83]
Microsilica	32.5 (2.0) [13]	33.1 (2.1) [13]
Fly Ash	10.8 (0.7) [4]	8.3 (0.5) [4]
Aggregates	kg/m^3 (lb/ft^3)	
Ceramic Beads	159.0 (9.9)	165.7 (10.3)
Glass Bubbles	43.4 (2.7)	41.4 (2.6)
Water/Cementitious	0.48	0.46
28 Day Strength MPa (psi)	5.6 (806)	3.4 (500)
Unit Weight kg/m^3 (lb/ft^3)	616.7 (38.5)	568.6 (35.5)
Concrete Strength to Weight	20.9	14.1

3.2 Reinforcement

While mix designs were nearing completion, the reinforcement design group began their testing of fibers and mesh reinforcement. The use of fibers can improve shrinkage cracking, impact resistance, and ductility of concrete.[5] These are all concerns when dynamic and repeat loadings occur on the canoe. For construction of the canoe, medium length carbon and polypropylene fibers were selected for testing. Two identical mixes were prepared. Polypropylene fibers were added to one while an equal volume of carbon fibers was added to the other. Plates were cast with each mix and tested in a five-point bending test. A 6.5 cm^2 (1in^2) fixture loaded the 305 mm by 305 mm by 13 mm (12 in. by 12 in. by 0.5 in.) plates, testing the different fiber reinforcements. Figure 2 displays the results of the plate tests.

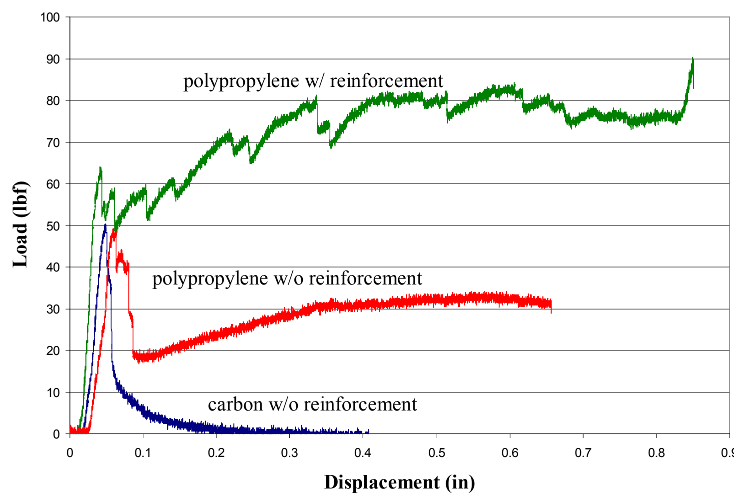

Figure 2: Plate Test Results

The plates containing carbon fibers were expected to sustain a higher load. Results validated this expectation, but the difference was small. Of greater interest was the result that the plates containing polypropylene fibers sustained loading under a larger deflection. As seen in Figure 2, the carbon plates failed to hold any strength soon after the peak load was reached. This is an effect of the carbon fibers being less flexible, resulting in a sudden failure. Additionally, carbon fibers increase permeability more than polypropylene fibers, which leads to a weaker concrete.[6,7] Test results and literature research led us to the use of polypropylene fibers.

Along with fiber reinforcement, mesh reinforcements are used to resist the larger stresses in the canoe. The reinforcement design group researched lightweight, high tensile strength meshes to resist and distribute loads beyond the points of application.

Three mesh reinforcement materials were chosen for testing: a plastic-coated fiberglass, a latex-coated fiberglass, and a polypropylene mesh. The tensile strengths were determined according to ASTM E 2098 using 51 mm by 305 mm (2 in. by 12 in.) strips. The two fiberglass meshes had high tensile strengths and elastic moduli; however, due to their increased stiffness, shaping them to the mold would prove difficult. Even though the polypropylene mesh had a lower strength, it was determined capable of resisting the stresses created in the canoe (See Appendix – Reinforcement Comparison). Added benefits of the polypropylene mesh were its ease of placement and it is light weight. The polypropylene mesh was two and five times lighter than the plastic-coated and latex-coated meshes, respectively, which minimized the weight increase due to the addition of mesh reinforcement.

3.3 Composite Action

Paddling, handling, and transporting create tensile stresses on both faces of the hull, and all must be considered when designing the cross-section. Realizing that concrete has low tensile strength, a mesh reinforcement layer near each face of the hull resists these stresses more efficiently than two layers at the center.

To test the performance of the composite section, as it would behave in the canoe, plates were cast and loaded as in the fiber testing. Once again, Figure 2 shows the performance of plates with and without reinforcement.

In addition, prestressing wires were used to aid in resisting the stresses created during the races. The goal was to reduce the magnitude of these tensile stresses in the hull. Six wires were used: two along the bottom of the hull, two halfway up the hull, and two along the gunwales. Each 1.6 mm (0.0625 in.) diameter steel wire was loaded to 1535 N (345 lbf). Once the wires were cut, an internal moment acting on the concrete precompressed the hull. In doing so, the wires increased the efficiency of our cross-section. The calculations given in the Appendix (Prestress Calculations) show that the maximum tensile stresses in the hull will not be reached under two or four person loadings.

4.0 Construction

A majority of this year's team had previous experience with two mold construction methods. Prior to last year, UW-Madison's teams had constructed their canoes by initially hand-tracing 305 mm (12 in.) AutoCAD sections onto plywood, cutting the sections with a jigsaw, and then pouring expandable foam between the sections. Because we lacked an accurate method of lining up the sections, previous molds contained significant error. For *Eclipse*, the team switched its method to milling 152 mm (6 in.) sections onto 19.1 mm (0.75 in.) medium density fiberboard (mdf) while incorporating a straight-line track to ensure accuracy in the mold. With these two options in mind, the *Mine Bender* team chose to mill the mdf sections, but added more accuracy to the mold, and sped up construction and finishing time.

With the *Mine Bender* hull design complete, the canoe was stationed into 76.2 mm (3 in.) or 152 mm (6 in.) sections, depending on location. Sections containing the modified flare—the first 91.4 cm (3 ft) of the bow—were cut every 76.2 mm (3 in.) to ensure the shape of the flare would be represented accurately, while remaining sections were 152 mm (6 in.). Figure 3 shows the bow mold sections of *Mine Bender*.

This file was then exported to AutoCAD, where a 45° lip along the gunwales and a vertical track down the center were added to the sections (see

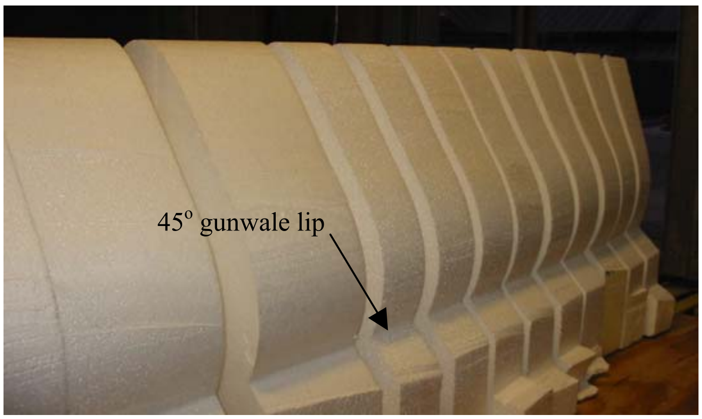

Figure 3: Bow Mold Sections

Figure 3). Modified from last year's 90° lip, the 45° angle allowed concrete finishers easier access to the gunwales, thus reducing finishing time at this area later in the construction process. Finally, a milling machine translated the AutoCAD file and cut all sections.

Once all sections were milled, a hot-wire cut blocks of polystyrene foam using the sections as guides. The polystyrene sections were then placed on a micro-laminated wood track (44.5 mm [1.75 in.] by 241 mm [9.5 in.]) positioned perpendicular to a strongback comprised of a steel I-beam and flat tabletop. Since the dimensions of the bow and stern end caps physically prohibited usage of the straight-line track, internal wooden dowels connected these sections. With all polystyrene sections cut and placed on the track, remaining imperfections were corrected using joint compound. The entire mold was sanded to an even finish and ultimately covered with window insulation, which acted as a concrete release agent.

One week prior to placement day, three diaphragms were precast and allowed preliminary curing time under controlled humid conditions. The day before placement, two layers of reinforcement were shaped and cut to fit the contours of the mold, and six prestressing wires were cut to length. Over thirty students constructed *Mine Bender* on January 26, 2002.

After placement of the first 3.18 mm (0.125 in.) lift of concrete, the diaphragms were positioned in their respective locations and held in place by reinforcement. Next, the first layer of reinforcement was worked into the concrete, with care taken to bury the reinforcement well within the first lift. A slurry mix consisting of Type III Portland cement and latex was painted onto the mesh, ensuring a better reinforcement-concrete bond between layers and preventing the reinforcement from absorbing water involved with the concrete mix. A second 3.18 mm (0.125 in.) concrete lift was placed, followed by the final layer of reinforcement, again incorporated with the slurry mix. The six prestressing wires were then stretched along the length of the canoe and tightened to their proper tension. This was accomplished by rigidly connecting the wires at one end to a steel stanchion fixed to the I-beam strongback, and securing the opposite end to adjustable turnbuckles attached to another stanchion. By covering the wires in the final 3.18 mm (0.125 in.) lift of concrete, the construction of *Mine Bender* was completed.

Within minutes of placing the final lift of concrete, a previously constructed humidity tent was placed over the canoe. Beneath this plastic tent, humidifiers maintained a proper environment for concrete hydration. After twenty-eight days of curing, the team removed the canoe from its mold. From this point, small pours for the construction of the bow and stern end plates followed. Additional patching, sanding, and finishing work continued until *Mine Bender* was ready for painting.

5.0 Project Management/Cost Assessment

Shortly after the 2001 NCCC, two project managers were chosen for the 2001-02 academic year based on their prior involvement and experience. These two project managers initially organized the team into core groups and selected group leaders (See Appendix – Project Planning). To assist these leaders, the project managers created detailed work schedules, allowing flexibility within a group, and incorporating deadlines for individual tasks (See Appendix – Time Management). This schedule consisted of all major activities involved with the canoe project.

In order to complete assigned tasks, group leaders assembled their own respective committees to achieve goals set by the project managers (See Appendix – Group Responsibilities). With numerous individuals on a team, tasks were completed according to deadlines, allowing the project to stay on schedule. Project managers supervised all activities and held frequent meetings with all members for summaries of completed tasks and discussion of upcoming assignments. Communication between all members was maintained through utilization of eProject on the Internet. eProject is a web-based application allowing private groups to organize and share information among its registered members. With the assistance of eProject, schedule changes, event announcements, and project updates could be reported and accessed quickly.

Team members were required to log hours by signing in and out of each work session, noting the number of hours and particular task for billing purposes. At the discretion of the project managers, each worker was assigned an employee label (Laborer, Technician, etc.) and billed out at his/her corresponding rate according to Section III.A.9.c.1 of the 2002 Rules and Regulations. Overall “direct labor” costs equaled $60,814 for the construction of *Mine Bender*. Additionally, an “expenses” charge totaling $2,518 was calculated by factoring material costs, outside labor costs, and a mark-up rate as specified by the 2002 Rules and Regulations.

Therefore, the overall production cost of *Mine Bender* was **$63,332**, 14% below our original cost estimate.

6.0 Summary

Increased focus on hull design and research led to the unique design of *Mine Bender*. By incorporating a modified flare in the bow, water is efficiently displaced, improving the seaworthiness of the canoe.

Additionally, great strides were made in mix design by realizing a lighter product does not necessarily indicate a better product. From this conclusion, the *Mine Bender* design team accepted a slight weight increase for a significant strength increase.

The Concrete Canoe Competition annually challenges students to become more proficient both technically and creatively. Members become leaders and crucial team participants. We are proud to present *Mine Bender* on behalf of the University of Wisconsin-Madison at the 2002 National Concrete Canoe Competition.