INSTANT WIN
Golden Canoe
Design Report Inside

DREXEL 2002

NET WT. 100 lbs (45.4 kg)

Certificate of Compliance

In accordance with Section III.A.8.a of the 2002 edition of the Rules and Regulations of the ASCE/MBT National Concrete Canoe Competition, the Canoompa Loompa's of the Drexel University Concrete Canoe Team do hereby certify the following:

The construction of ***Canoompa Loompa*** has been performed in complete compliance and strict adherence with the rules and regulations of the national competition as outlined in Section II, "Design and Construction Requirements;"

The participants intended to represent Drexel University at the 2002 ASCE/MBT Concrete Canoe Competition are qualified student members as specified under Section I.G, "General Rules and Eligibility Requirements." The registered participants are civil engineering students during the 2001/2002 academic year, have contributed to the design and construction of ***Canoompa Loompa*** and are members in good standing of the Drexel University ASCE Student Chapter;

Canoompa Loompa has been completely designed and constructed within the 2001/2002 academic year as required by Section II.B.1; and,

The design paper, oral presentation and display board have been prepared in accordance with the rules and regulations of the national competition as outlined in Section III, "Academic Requirements."

The rules and regulations referred to in this statement include all subsequent rulings and clarifications handed down by the Committee on National Concrete Canoe Competitions (CNCCC). Drexel University has furnished documentation as part of the Appendix to this report. Drexel shall furnish any further documentation necessary, such as CNCCC rulings and any additional MSDS information, to the judges or the CNCCC immediately upon request.

Donna Charland
Competition Manager, ***Canoompa Loompa***
2002 Drexel University Concrete Canoe Team

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Canoompa Loompa

The Drexel University ASCE Student Chapter proudly represents the Penn-Delaware Region at the 15th Annual ASCE/MBT National Concrete Canoe Competition, hosted by the University of Madison-Wisconsin, Madison, WI, June 21-24, 2002.

Editor: *Travis Taylor*

Canoompa Loompas

2002 Drexel Canoe Team

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It's Scrumdidilyumptious!

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Introduction & Executive Summary

"No other factory in the world mixes its chocolate by waterfall. But it's the only way if you want it just right." – **Willy Wonka**

Unfortunately, the same cannot be said about mixing concrete. For the past decade, engineering students from Drexel University have dedicated countless hours to the design and construction of a high-performance concrete canoe in an effort to claim a national championship. Founded in 1891 by Anthony J. Drexel, a Philadelphia financier and philanthropist, Drexel University consists of six colleges with a combined enrollment of 11,000 and operates one of the nation's oldest and largest mandatory co-operative education programs. Located in the University City area of Philadelphia, Drexel is ideally situated for its valuable relationship with the business and industry of the nation's fifth largest metropolitan area.

This year marks Drexel's sixth overall (fifth consecutive) appearance as the Penn-Del regional representative at the ASCE/MBT national competition. Our four previous canoes – *Rocky Canoa*[1] (1998), the *Broad Street Bully*[2] (1999), the *Drexel Experiment*[3] (2000), and *Obi-Wan Canoebi*[4] (2001) – have finished 11th, 8th, 13th, and 7th, respectively. We continue to strive to best our 6th place finish of *Goodnuf* at the inaugural national competition held in 1988.

Our 2002 entry is christened ***Canoompa Loompa***. This is in honor of the Oompa Loompas, the green-haired, orange-faced pygmies who spent countless hours in Willy Wonka's Chocolate Factory making the marvelous surprises that awaited five lucky holders of a "Golden Ticket" found in his candy bars. Our canoe is 6.6 m (21.7 ft.) long and has a mass of 45.4 kg (weight of 100 lbs.). It features a beam width of 648 mm (25.5 in.), a depth of 305 mm (12 in.), and 25 mm (1 in.) of rocker. The lightweight matrix is an epoxy-modified cement mortar with a unit weight of 763 kg/m^3 (47.6 pcf) and 28-day compressive and tensile strengths of 5.8 MPa (840 psi) and 1.2 MPa (170 psi), respectively. It is reinforced with several layers of a glass fiber mesh, strips of carbon fiber mesh and strands of polypropylene fibers. The nominal thickness of the canoe is 10 mm (0.4 in.).

Through careful evaluation of previous designs, we refined the hull geometry to maximize speed and eliminated several features that resulted in a decrease in construction time without adversely affecting the canoe's performance. Utilizing an extensive database of mix designs, an aggressive design-build schedule, and years of experience, the end result is the lightest, and arguably the best, concrete canoe in Drexel's history. Painted metallic gold with black and purple lettering, it is our hope that ***Canoompa Loompa*** will be our "Golden Ticket" to a victory at this year's National Concrete Canoe Competition in Madison, Wisconsin.

Hull Design

"A thing of beauty is a joy forever." – **Willy Wonka**

Canoompa Loompa represents over six years worth of experimentation and refinement in producing racing hulls that integrate naval architecture with reinforced concrete design. Since 1996 when Drexel began placing considerable emphasis on hull design, our teams have continually focused on the development of a canoe that has the optimum balance of speed, tracking, stability, and maneuverability. Over the years, we have evaluated the performance of previous canoes, obtained feedback from our paddling teams, and made observations of the designs and performance of national qualifiers in order to refine our canoe designs. Based on this wealth of experience and knowledge, slight modifications have been incorporated into subsequent hull configurations to achieve ideal performance. By taking into account the principles of hull design[5,6], and the increased skill of our paddlers, key parameters such as length, beam width, cross-sectional and longitudinal shape, and rocker have been adjusted and implemented in ***Canoompa Loompa***'s sophisticated hull.

Last year, most of the hull design effort was concentrated on increasing the speed and tracking of our canoe, *Obi-Wan Canoebi*[4]. This was done at the expense of maneuverability and stability both of which were considered less of a concern due to the experience of our paddlers. While *Obi-Wan Canoebi* did perform satisfactorily in terms of maneuverability and tracking, we envision that we are still capable of attaining a higher hull speed. Therefore, the primary goal was to maximize speed without significantly impacting other performance attributes. Secondary issues such as paddler efficiency, ease of construction, weight, and cost were also taken into account. To this end, this year's hull was refined in several key areas, including:

- Increase in the length of the canoe for increase in theoretical hull speed,
- Narrowing of the beam width for greater speed and better paddler ergonomics, and
- Removal of several extraneous design features in an effort to reduce weight and construction time.

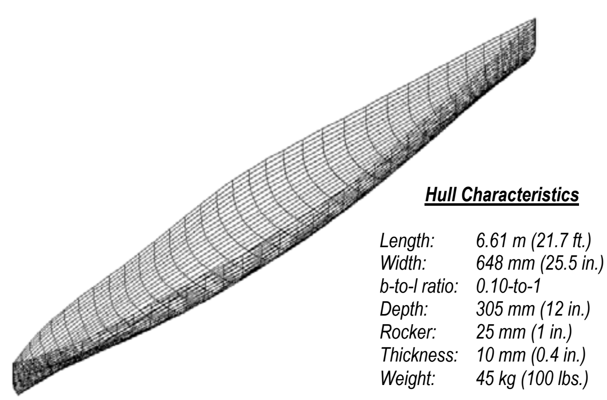
At 6.6 m (21.7 ft.), ***Canoompa Loompa***'s (Figure 1) length falls within the range shown by Drexel[1-4] and others[7-10] to provide superior speed and maneuverability. The increase in length of nearly 0.25 m (10 in.), compared to last year's canoe, increases the hull speed and tracking, but does decrease it's maneuverability. A sharp bow is maintained at the entry line reducing strike-through resistance thereby enhancing streamlining. The canoe widens smoothly until it reaches its maximum beam width of 648 mm (25.5 in.) just aft of amidships. This form is typical of most sophisticated racing hulls that have their fullness shifted slightly to the rear, making the bow finer at the expense of stern resulting in an efficient design that balances speed, load capacity and stability[5,11].

The maximum width results in a beam-to-length ratio of 0.10-to-1, smaller than the typical 0.11-to-1 used in previous Drexel canoes. This slight reduction directly corresponds to an increase in speed and tracking with only a minimal reduction in stability and maneuverability. The beam is narrow enough to allow efficient paddling, but remains wide enough for paddler comfort.

In a concerted effort to decrease construction time and produce the lightest concrete canoe ever made by Drexel, several features used in previous designs were eliminated. One of the hallmarks of our canoes was a "whale tail" in the stern section. This flaring out of the sidewalls above the waterline allowed the stern paddler to sit further back for better control of the canoe. After careful consideration, our designers concluded that this feature was not necessary and its elimination would not result in a decrease in performance. Several of our canoes[2-4] used a thickened gunwale and thwarts to increase hull stiffness, while one design[1] did not use either. Upon further evaluation, it was determined that because the proper combination of hull shape and material selection was made, these stiffening elements were not required. An added benefit in the removal of these features was a reduction in mass (weight) of nearly 9 kg (20 lbs.).

The hull incorporates 25 mm (1.0 in.) of rocker for increased maneuverability while a depth of 305 mm (12.0 in.) was maintained to allow enough freeboard during the 4-person co-ed race. The shallow arch cross section provides a high resistance to capsizing. The section has a surface-to-volume ratio with low wetted surface area, reducing the skin friction that is the primary contributor to resistance at paddling speeds[6]. The arched bilge combines the maneuverability and stability of the flat bottomed-cross section with the speed and tracking of the rounded section resulting in a well-balanced and structurally efficient design.

Figure 1 – Canoompa Loompa Hull Configuration



Structural Design

"Invention, my dear friends, is 93% perspiration, 6% electricity, 4% evaporation, and 2% butterscotch ripple." – **Willy Wonka**

Concrete Mix Design

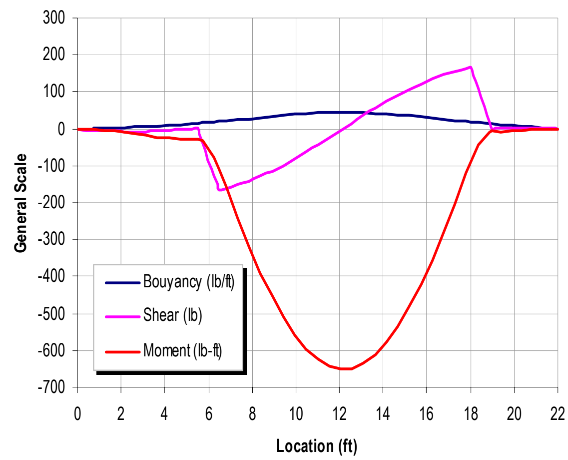
Based on the fact that the hull geometry of ***Canoompa Loompa*** was not designed to be significantly different from that of the last several years, the results of the structural analysis for *Obi-Wan Canoebi* were used to determine the target properties for the reinforced concrete composite. The structural analysis takes into account the weight of the canoe and paddlers and the reacting buoyancy loads to determine the corresponding shear forces and bending moments (Figure 2). The case of loading where the greatest bending stress is encountered is when the canoe is simply supported. However, the worst case loading condition in the water is evaluated in design practice[12]. This loading condition occurs when the load of the men's tandem, assuming paddlers with a mass of 83 kg (weight of 185 lbs.) each, is applied to the canoe.

The cross sections where maximum bending moments and shear stresses occurred were used to determine the necessary compressive and tensile strengths. Using the results of the analysis and incorporating a factor of safety of 2, the required compressive and tensile strengths are 1.8 MPa (260 psi) and 0.9 MPa (130 psi), respectively. In addition to the strength requirements, several key properties were targeted including:

- A unit weight under 800 kg/m^3 (50 pcf),
- Low water absorption,
- High durability, and
- Good workability and finishing properties.

Over the past several years, Drexel has created an extensive database of concrete mixes based on its own designs and testing with the results of several schools competing at the national level. Using this database, we were able to select several mix designs for consideration. Being too conservative in past years, our designs tended to exceed the aforementioned design parameters.

Figure 2 – Bending Moment and Shear Diagram



Therefore, we selected the mix with the lowest unit weight that would meet the minimum strength requirements for extensive testing.

Historically, Drexel was one of only a handful of schools in the nation to use epoxy-modification in its concrete mixture designs. Last year, we deviated from using epoxy and used acrylic latex as a binding agent. In retrospect, this became a problem with the overall quality of our final product. Following construction, severe alligator cracking of the surface layers formed raising concerns that the concrete could scale off. Fortunately, that did not occur. For this reason, we returned to using epoxy in our final mix design, which prior experience has told us forms a reliable finished product, without compromising strength or workability.

The proportioning of concrete constituents was done following the Absolute Volume Method and all testing was done in accordance with the appropriate industry standards. Unit weight (ASTM C138)[16] and tensile strength tests (ASTM C496)[19] were conducted on 50 mm by 100 mm (2 in. x 4 in.) cylinders. According to ASTM C39 specifications[13], compression tests conducted on cylinders are limited to concrete with unit weights in excess of 800 kg/m^3 (50 pcf). We determined that the mix design would be similar to a hydraulic cement mortar (ASTM C219)[18] rather than a concrete (ASTM C125)[15]. Therefore, compression tests conducted on 50 mm (2 in.) cubes following ASTM C109 procedures[14] were determined to be the applicable standard.

Table 1 shows the mix proportions, unit weight and strength properties of our selected mix, *Gloop*. For comparative purposes, last year's mix design is provided. At 763 kg/m^3 (47.6 pcf), *Gloop* has the lowest unit weight of any mix ever used by Drexel in its concrete canoe. Its 28-day compressive and tensile strengths are 5.8 MPa (840 psi) and 1.2 MPa (170 psi), respectively. It is an epoxy-modified Portland cement mortar that is comprised of Type I Portland cement (ASTM C150)[17], an epoxy resin/hardener system; low-density microsphere aggregate, high-range water reducer, strands of polypropylene fibers, and water. Although the strengths of the latex-modified concrete are slightly higher, *Gloop* has a lower unit weight, meets the given strength requirements, and resulted in a superb final product.

The epoxy resin/hardener system consists of *EPI-REZ® Resin WD-510*, and *EPI-CURE® 3072 Accelerated Amidoamine Curing Agent*. The system forms a fine particle size emulsion specifically designed for water dilution prior to admixing with cement. The epoxy modification results in increased tensile and flexural strength properties. An additional benefit of the epoxy is a lower permeability due to the solidification of the epoxy in the air voids within the concrete matrix.

Table 1 – Mix Proportions and Engineering Properties

Mix Design	*2001 Mix*	*Gloop*
Binding Materials, kg/m^3 (pcf) [% by weight]		
Portland Cement	373.40 (23.30) [86%]	339.90 (21.21) [75%]
Latex	62.50 (3.90) [14%]	0 (0)
Epoxy Resin	0 (0)	75.53 (4.71) [16.7%]
Curing Agent	0 (0)	37.77 (2.36) [8.3%]
Aggregate, kg/m^3 (pcf)		
Microspheres	112.18 (7.00)	113.30 (7.07)
Admixtures & Additions, kg/m^3 (pcf)		
HRWR	0 (0)	13.62 (0.85)
Polypropylene Fibers	0.80 (0.05)	0.80 (0.05)
Water (batch)	261.38 (16.31)	181.85 (11.30)
w/c Ratio *	0.70	0.58
Engineering Properties		
Unit Weight	810 kg/m^3 (50.6 pcf)	763 kg/m^3 (47.6 pcf)
Compressive Strength	6.5 MPa (940 psi)	5.8 MPa (840 psi)
Tensile Strength	1.4 MPa (210 psi)	1.2 MPa (170 psi)
Workability	Good	Excellent
Water Absorption	Low	Low

* *w/c ratio includes water from admixtures and aggregate*

The aggregate selected was *Q-Cel®*, a low-density, hollow, sodium borosilicate microsphere aggregate that added volume while reducing the overall concrete density. High-range water reducer (HRWR) was used to maintain a low water/cement ratio while achieving good workability, thus allowing higher strengths at a lower unit weight. Finally, strands of polypropylene fibers were dispersed in the concrete to help prevent shrinkage cracks from forming and to hold any cracked sections together.

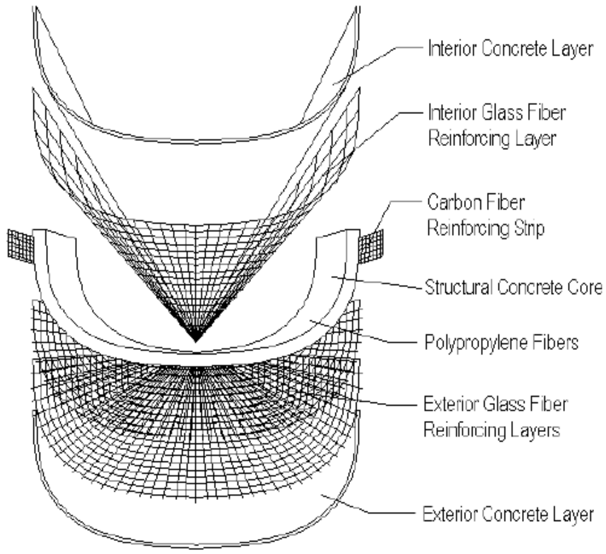
Reinforcement and Composite Action

The concrete composite must resist all shear forces and moments generated during various loading conditions while in transport, on display, and in competition. Our requirements for reinforcement were to limit hog and sag deformations, obtain considerable impact and cracking resistance, and maintain a thin, lightweight section. Lastly, all materials and the selected scheme were to be in conformance with all of the regulations[20].

Our team selected a glass fiber mesh to serve as the primary reinforcement in our canoe based on proven performance in past designs, the satisfaction of all design criteria, and the team's familiarity with its use in construction. The glass fiber has excellent engineering properties including high tensile strength, a high modulus of elasticity of 72.5 GPa (10.5 x 10^6 psi), and low elongation. The reinforced concrete also has increased impact and cracking resistance, low weight, and the tractability to maintain thin, flexible sections[21]. The particular reinforcement used is a 203 g/m^2 (6.0 oz/yd^2) leno weave mesh with 3.2 mm (0.125 in.) square apertures. Grab-tensile tests (ASTM D4595)[22] indicate that a single layer could withstand an average tensile load of 35 kN/m (200 lb/in).

To compensate for the removal of the stiffening elements, a 25 mm (1 in.) wide carbon fiber reinforcing strip was placed around the canoe near the gunwale. The 341 g/m^2 (10.1 oz/yd^2) carbon fiber mesh has a modulus of 231 GPa (33.5 x 10^6 psi) and a tensile strength of 3.65 GPa (530,000 psi). This reinforcing strip provides high strength and high modulus at a fraction of the weight of the thickened reinforced concrete gunwale and thwarts.

Figure 3 – Exploded 3-D View of Hull Skin



Implementing these materials, the hull skin is a composite of an epoxy-modified cement mortar sandwiched between layers of glass fiber mesh (Figure 3). Based on the calculated compressive and tensile strengths, the selected reinforced concrete composite provides more than an adequate factor of safety against failure. This was proven by performance tests conducted on 200 mm by 200 mm by 10 mm (8.0 in. x 8.0 in. x 0.4 in.) simply supported plates loaded in order to induce the stresses anticipated during worst case loading. A load of 123 N (28 lbs.) is required to obtain the stresses in the unreinforced concrete section. During testing, the reinforced composite withstood 551 N (124 lbs.) indicating that it could easily withstand the required service loads.

Construction

"Oh, you should never doubt what no one is sure about." – **Willy Wonka**

The construction of ***Canoompa Loompa*** was performed with the use of a male mold comprised of masonite templates and expanded polystyrene (EPS) foam blocks. This time-tested construction technique has been used by Drexel to produce canoes over the past several years[23].

Naval architecture software generated the full-scale plans for mold construction. The mold skeleton consisted of 42 cross-sectional templates, aligned at 150 mm (6 in.) intervals along a wooden strongback, and longitudinal templates for both the bow and stern sections. Blocks of EPS foam were secured in between the sections and cut with a nichrome hot wire using the templates as guides. Strips of plywood were inserted 25 mm (1.0 in.) deep into incisions cut along the shear line to serve as guides for casting. The mold was refined by filling in imperfections with drywall compound and faired by sanding with long-boards. It was then hardened with epoxy resin and coated with mold release wax prior to concrete casting.

Construction of the canoe began by placing a single layer of glass fiber mesh in immediate contact with the mold. A 6 mm (0.25 in.) thick layer of concrete was then applied using plastic tubing positioned transversely at 305 mm (12 in.) intervals to gauge the thickness. Once the concrete was placed, the plastic tubing was removed and the voids left by the tubing were filled. A 25 mm (1 in.) wide strip of carbon fiber mesh was then embedded in the concrete approximately 25 mm (1 in.) from the shear lines followed by two layers of glass fiber mesh. An exterior coat of concrete was then applied to provide full coverage over the reinforcement. Throughout the casting process, unit weight determinations of fresh concrete were made and cylinders and cubes were obtained for quality control.

The canoe was moist cured continuously for 14 days under saturated towels in a plastic tent with two humidifying units. After curing, the canoe was released from the mold. Sanding commenced using planar long-boards to give a smooth curvilinear finish. Thin patches of concrete, with the same mix design used in the original casting, were applied to fill imperfections.

The finished ***Canoompa Loompa*** provides a continuous 813 mm (32 in.) band of exposed concrete. The interior portion of the band was left uncoated, while the exterior portion was coated with a polyurethane water sealant. The remainder of the canoe was finished with several layers of automotive primer, acrylic enamel paint and clear coat. The final touches to the canoe were the application of stenciled vinyl lettering and decals.

Project Management & Cost Assessment

"So much time and so little to do. Wait a minute! Strike that! Reverse it!" – **Willy Wonka**

In July 2001, our team implemented a management hierarchy (provided in the Appendix) that was broken down into three general areas: Engineering and Construction, Competition, and Administration. Senior team members volunteered to fill key positions including project manager, competition manager, and administrative director. A graduate-level student, our most experienced team member, served as the principal engineer. During the first month of the academic year, various positions including project engineers, foreman, display manager, and paper editor were filled.

The engineering and construction manager was responsible for coordinating the efforts of the engineers and technicians on the project. The competition manager coordinated all efforts associated with display board construction, preparing the oral presentation, writing the technical paper, and paddler training. The administrative director was responsible for various aspects including fundraising and public relations.

The principal engineer served as the technical expert reviewing the findings of the project engineers, offering guidance on various aspects of design and construction, and assuring compliance with all rules and regulations. Project engineers reported to the project manager on issues regarding scheduling, materials, and labor, and met regularly with faculty advisors and consultants to complete the design phase of the project. The foreman carried out the construction plans for the mold and the canoe while all technicians and laborers worked in separate focused teams under the supervision of graduate engineers and the foreman.

A detailed schedule was developed in July 2001 for this unique design-build project to determine critical paths and establish milestones. A simplified version of this schedule is provided in the Appendix. Weekly meetings were held to maintain communication, update the status of the project, and set short-term and long-term itineraries, while e-mail was used extensively to pass meeting minutes to all parties.

The overall cost for ***Canoompa Loompa*** is approximately $94,200 and includes all costs associated with the research and development and the construction of the canoe. This is considerably less than the $110,000 estimate that was based on last year's canoe. A total of 1195 hours of labor were spent on this project in preparation for the 2002 ASCE/MBT National Competition. A detailed cost assessment, based on established unit costs and hourly wages[20], is presented in the Appendix. The direct labor costs totaled just over $90,000 and include the Direct and Indirect Employee Costs multipliers of 1.4 and 1.25, respectively, and a profit of 15%. A total of $1,240 was spent on materials while all other direct expenses amounted to about $2,860. Both of these costs include a 10% markup as required in the regulations[20].

Summary

"And Charlie, don't forget what happened to the man that suddenly got everything he ever wanted. He lived happily ever after." – **Willy Wonka**

Following our 7th place finish at the 2001 National Competition, the ***Canoompa Loompa***'s of Drexel University targeted several key areas in the hope of creating our "Golden Ticket" to a national concrete canoe championship. Through careful evaluation of previous designs, our team refined the hull geometry in order to maximize speed. Furthermore, we eliminated several features in order to decrease construction time and reduce the overall weight, while not compromising overall performance. Using an extensive database of concrete mix designs, an aggressive design-build schedule, time-tested construction techniques and years of experience, the lightest, and best, concrete canoe in Drexel's history was created.

It appears that we suddenly got everything we ever wanted. Perhaps after this year's competition, we will live happily ever after.