"The Concrete CANEW - A Competitively Aggressive, Novelly Engineered Watercraft"

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Abstract

This paper presents an overview of the ASCE/MBT National Concrete Canoe Competition and includes tips for getting involved as a major competitor. The steps taken by a team from the University of Alabama in Huntsville (UAH) to build a boat called the "CANEW" are described. The acronym, which stands for a Competitively Aggressive Novelly Engineered Watercraft, is UAH’s attempt to completely redefine the meaning of the word.

The UAH team placed first in the design report category at this year’s competition and won the races by a one point margin. Their design was featured in the Wall Street Journal and the CANEW was selected as the best product at the competition.

Introduction

The National Concrete Canoe Competition is sponsored by the American Society of Civil Engineers (ASCE) and Master Builders, Inc. of Cleveland, Ohio. This unorthodox competition is intended to give students hands-on experience by challenging them to apply sound engineering principles to design and race a concrete canoe. The origin of the competition can be traced to the 1960's when several ASCE student chapters held intramural races. The University of Illinois at
Urbana and the University of California - Berkeley both claim that they held the first regional competitions in the early 1970's (ASCE 1972). The competition was elevated to the national level in 1988, and regional winners have carted their canoes across the United States every year since in their quest to become the national champion. In every sense of the word, the competition has become, "A Race to Innovate" (Gilbert 1997).

At the competition, the top teams from across the US and Canada are judged on oral and written presentations detailing each canoe's design, construction and materials; distance and sprint races on the lake; and, a "swamp test" in which submerged canoes must pop up and float. A typical national contingent consists of approximately 25 university teams that qualify as finalists during regional competitions.

Through the years, the competition has become highly competitive, and is often referred to as the America's Cup of college civil engineering. Nearly 250 schools from across the country currently compete at the regional level. All five of the previous winners were in contention at this year's national competition including four time winner and defending champion UAH, host school Florida Institute of Technology, the South Dakota School of Mines and Technology, four time winner University of California - Berkeley, and Michigan State University. Last year's runner-ups from California State - Sacramento and Clemson University also qualified along with the Canadian National Champion from the Ecole de Technologie Superieure.

There are currently no dimensional restrictions placed on the hull and teams must build a new boat every year. Sixty percent of the competition is scored based on the technology underlying the hydrodynamic and structural designs. The remaining forty-percent is awarded for performance.

At the competition, consistency is very important. This year, for example, Clemson University won over UAH by the smallest margin in history. The team from Oklahoma State finished third. Clemson's win was facilitated by the theatrics, promotion, and advertising associated with their "Sequel." Their display consisted of a full scale marquis designed to promote the canoe and accentuate the fact that they would dominate the competition again this year in the water. The team followed this production by a multi-screen Power Point presentation based on a film critic's commentary of their plans to unseat UAH as the defending champion. To their credit, both of these Broadway performances were remarkable and unparalleled in the history of the competition.

UAH edited the final chapter of the Sequel by winning the races. We also paced first in the design report, won the coveted award for the best product, and placed fourth in the visual presentation. However, our eleventh place finish in the display category was disappointing, and gave Clemson the edge that they needed to win. But winning the national championship takes much more than consistency. The major obstacles to success are the failure to cope with human dynamics and mental discipline.

**Conditioning to Win**

Many students find the concrete canoe project one of the most challenging, but rewarding, experiences that they have had. In general, it is not because the work is difficult to do but because the effort requires a systematic approach to problem solving. All of the top contenders at the national level are forced to develop comprehensive and flexible game plans that include mechanisms to solve the problems that they face. This process often begins with mental conditioning.

First and foremost, a team must always think that they want to, and that they can, become a winner. This does not necessarily mean placing first in the competition, but that the contingent can truly say that they have done their best to define problems, identify objectives, explore issues, plan courses of action, solve
problems, and review solutions.

At the inception of this year’s concrete canoe effort, for example, the members of our chapter outlined plans to develop an engineering environment that fostered innovation and creativity. We discussed why some engineering teams are more productive than others, and what kind of leadership is required to facilitate success.

In the process of designing and building our boat, we addressed pertinent hydrodynamic and structural issues. Our members conducted extensive research and documented findings in written and oral reports. Each of us developed a vested interest in the chapter and took pride in making independent contributions while working toward a common goal. As the concrete canoe project progressed, we integrated our ideas so well that we exceeded our own expectations.

**Hull Design**

Experienced canoeists and paddlers know that not all canoes are created equal. One of the most important factors to consider is hull design. For a newcomer to the concrete canoe competition, the best approach is to simply ask ASCE’s Office of Student Services for copies of the top five designs reports from the most recent national concrete canoe competition. Look carefully at the boat that finished first and determine what sets it apart from the pack. If the attributes are not obvious, duplicate the design. Provided that your team can match their paddling prowess, your new boat will force your major opponent to aggressively innovate in order to win again in the water. At UAH, we never underestimate our competitors and always review the top reports in great detail.

This year, our goal was to design a hull shape having the correct balance of speed, tracking, and maneuverability required to achieve maximum performance under all racing conditions. To meet this goal, we drew from the vast knowledge base accumulated by our predecessors who compiled extensive literature surveys, experimental data, analytical results, race statistics, films, photographs, and personal recollections. As a result, we established and prioritized the desired attributes as (1) outstanding straight line speed, (2) good turning ability, (3) advanced ergonomics, (4) ease of construction, (5) acceptable stability, (6) minimum wetted surface area, (7) adequate freeboard, and (8) acceptable tracking.

![Graph showing performance characteristics](image)

The plot in Figure 1 shows the performance characteristics of our most recent entry, the "CANEW." At maximum output, a two man crew generates the equivalent to a maximum steady state output of 110.8 N (24.9 lb), and can therefore achieve a speed of 4.27 m/sec (14 ft/sec). The new boat is radically different from its predecessors and all other commercially available canoes. The attributes of our remarkable creation are highlighted in Figure 2.

The boat is 6.7 m (22 ft) long and has a mass of 34 kg (equivalent to 75 lb), a maximum width of 78.7 cm (31 in.), and a maximum depth of 30.5 cm (12 in.). A 657 kg/m$^3$ (41 lb/ft$^3$) concrete mix, having an average 28-day strength of 1.58 MPa (229 psi), was used to produce the hull. The concrete was placed by hand over two layers of a graphite mesh separated by a Mylar
honeycomb. The nominal wall thickness is 0.76 cm (0.3 in.). The boat is dark blue with multicolored attributes.

**Structural Design**

The stress distribution in the hull of a concrete canoe continuously changes when the canoe is paddled. The critical sections, located directly beneath the paddlers, are subjected to a combination of bending and shear loads. They, and other areas, often experience reverse bending when the canoe is transported and raced.

Past research has shown that the best way to resist the compressive and tensile stresses produced by reverse bending is to place layers of reinforcement symmetrically in the composite section. The moment of inertia created by this "adaptive" reinforcement scenario is increased by separating the layers as far apart as possible; stresses are driven to these layers by the use of a relatively flexible concrete (Biszick and Gilbert 1999).

Figure 3 illustrates the composite section used to fabricate the "CANEW." We placed concrete over two layers of a graphite mesh separated by a Mylar honeycomb. The structural design relies on the fact that whenever the section is bent in either direction, one of the graphite layers goes into tension while the other goes into compression. Although the mesh does not take any compression outside of the composite section, it becomes amazingly stiff when embedded.

The compressive modulus of the embedded mesh can be computed by measuring the deflections of a composite plate during a simple bending test. These deflections provide a measure of the flexural stiffness EI, where I is the moment of inertia of the transformed section and E is the elastic modulus of the base material (concrete). Since E is known, I can be computed. It is then a simple matter of using computer techniques to vary the unknown compressive modulus of the reinforcement until the moment of inertia of the transformed section agrees with the experimentally determined value. During this calculation, the load bearing capacity of the concrete on the tension side of the section is taken into account, along with the local moment of inertia of the reinforcement about its own centroid.

We used this unique approach to study reinforced composite sections of different but constant thickness, constructed using a number of different concretes. All factors considered, we chose to use a 5.6 mm (0.22 in.) thick Mylar honeycomb to separate the graphite layers. The honeycomb acts as a uniform spacer and carries the shear loads. It can be conformed to nearly any shape, and if the material is slightly overexpanded, it becomes isotropic in the principal directions. Graphite has a modulus close to that of steel but is five times lighter. Its high yield strength (tens times higher than steel) allows the graphite to
absorb most of the stress in the composite section.

**Concrete Mixture Design**

The purpose of designing a concrete composite structure is to combine several materials to obtain better performance than can be achieved by using one of the materials alone. The structural performance decreases when a constituent fails or is underused.

In designing the "CANEW," we needed our mix to withstand the rigors of the competition without cracking and contribute significantly to overall performance. The mix proportions in kg/m$^3$ (lb/ft$^3$) were Portland cement: 396 (667), latex: 132 (222), micro-balloons: 57 (96), and water: 395 (665). The fairly low strength [1.58 MPa (229 psi) at 28 days], polymer-modified concrete has a low elastic modulus [0.030 GPa (0.0044 Msi)] that enables the reinforcement to absorb the dangerous stresses that result from the reverse bending that takes place in the critical sections located directly beneath the paddlers. The small and uniformly sized micro-balloons create a dense grain structure that helps prevent the graphite fibers from buckling on the compressive side of the composite section. The mix has a water to cement ratio of 1.0 and a unit weight of 657 kg/m$^3$ (41 lb/ft$^3$).

**Winning Strategy**

If a team wants to become, or remain, a serious competitor, they must plan their efforts as soon as the fall semester or quarter begins. Decide on a design, do some testing, and get a mold built right away. Fabricate a prototype to test the design and train your crew. Once satisfied with the design, place your concrete canoe as soon as possible.

While working on the boat, discuss a theme, choose one, and revolve your efforts around it. Take plenty of pictures, keep good records, and make notes as you go. Draw attention to your efforts and always be on the lookout for potential sponsors. Make them aware that their donations are tax deductible and offer to place their logos on your web site with direct links to their companies.

At the competition, assign team members to document every school's effort. Select the best attributes of their displays, final products, oral presentations, and design reports, and then incorporate these into your future deliveries. Never get discouraged if you make a mistake, and always strive to do well in all of the events to give your team the best chance of placing in the top five.

**References**

