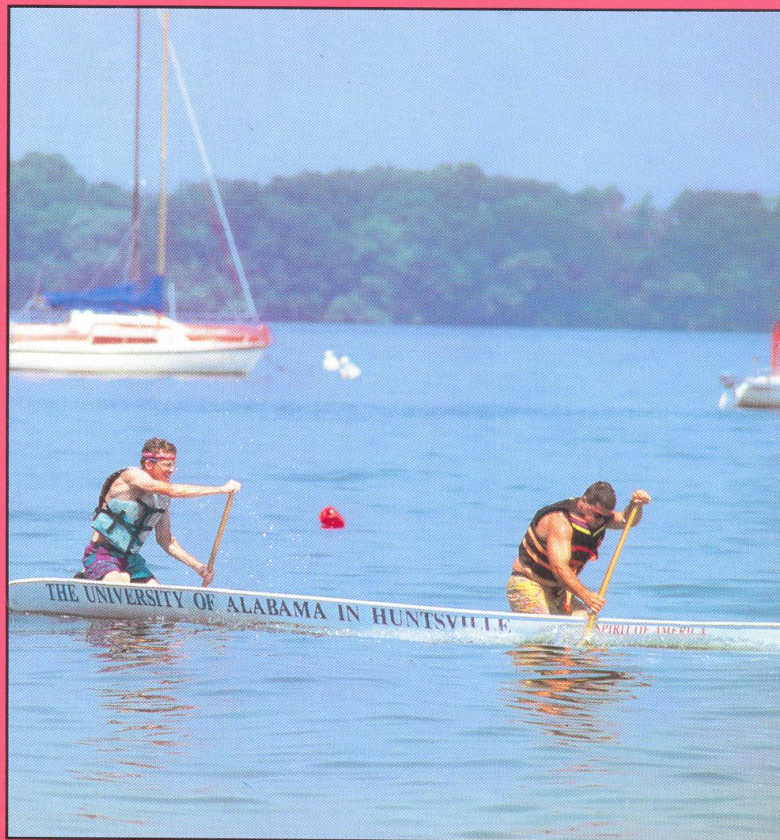


Experimental Techniques

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Technical Notes

EXPERIMENTAL TECHNIQUES TO UNDERSCORE A CONCRETE VICTORY

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A team from the University of Alabama in Huntsville (UAH) emerged victorious at the 1996 National Concrete Canoe Competition held in Madison, Wisconsin, June 13-16, 1996. The win, backed by an arsenal of analytical and experimental techniques to create what is now the longest, lightest and fastest concrete canoe ever raced at the national level, earned UAH its third National title in four years.

UAH's 1996 entry, christened the *Spirit of America*, was 21 ft. 2 in. (6.4 m) long and weighed 78 lbs. (347 N). It was 34.5 in. (87.6 cm) wide, 10 in. (25.4 cm) deep and 0.2 in. (5 mm) thick. The canoe was produced by placing a 35 lb./ft.³ (561 kg/m³) concrete mix, having an average 28-day strength of 510 psi (3.5 MPa), over an advanced composite mesh made of steel and geotechnical material. The concrete had a

density much less than that of fresh water [62 lb./ft.³ (994 kg/m³)] and the reinforced composite section actually floated.

In designing the canoe, empirical results were used to tune commercially available, hydrodynamic software supplemented with custom computer codes. Over the past five years, for example, several different one-third scale models were pulled through the water at various speeds and through waves of different heights. Strain gage transducers were used to measure drag while optical switches and a coded wheel kept track of the motion. In other tests, strain gage transducers were used to measure the drag as full scale prototypes were pulled through the water using a powerboat. The forces generated by team members while paddling were measured using strain gages mounted on the paddles. This data was coupled with optimization software to design a boat having outstanding straight line speed, good turning ability and advanced ergonomics.

At this race, UAH introduced the method of stereolithography as a rapid prototyping tool to streamline the lengthy design-to-part process. This approach involved

translating a CAD drawing of the canoe to a solid model by directing ultraviolet laser radiation onto a vat of liquid photopolymer. The 1/20 scale model enabled the hull shape to be visualized. Since the photopolymer was birefringent, the overall stress distribution in the model could be observed using a polariscope.

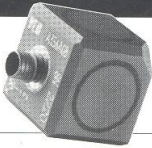
Once the shape was established, full-scale computer generated cross sections were used to produce plywood templates. The templates were mounted and aligned on a wooden strongback with the help of a laser. Foam insulation board was rough cut and glued between the templates. After the foam was faired to accommodate the intended shape, the male mold was evaluated using optical contouring techniques including shadow moiré. A fiberglass practice canoe was constructed and used to verify the hydrodynamic design. The experimental results agreed to within a few percent of the analytical predictions, leaving the formidable task of duplicating the product in reinforced concrete.

The stress distribution in the hull was initially characterized by carefully reviewing finite element results and the isostatics (cracks in the directions of principal stress) which had developed in older concrete canoes. This review was supplemented with data taken from strain gages mounted at critical locations on the older boats. The experiments provided accurate real-time data which quantified the dynamic loads and the stress reversals which occurred while paddling. The experimental results were used to select the geometry and materials for the cross section and to establish the minimum concrete compressive strength required for the canoe.

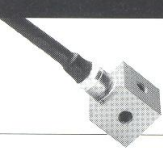
The construction scenario for the *Spirit of America* began by producing birefringent models for several different reinforcement schemes. After studying many different geometrical configurations in a polariscope, it was clear that an extremely efficient section could be produced by placing two layers of steel reinforcement as far apart as possible in the composite section. The transformed section method was used to quantify the stresses for various concrete mixtures. By reducing the stiffness of the concrete rather than concentrating on increasing its compressive strength, the team produced an extremely efficient, under-reinforced composite section in which steel failed before the concrete. In the process, they introduced an entirely new design approach for creating thin-walled concrete panels.

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