Five Years of Solar Powered Boat Racing at Marquette University

Robert L. Reid, Bruce D. Hoeppner
Marquette University
Milwaukee, Wisconsin

Abstract

Marquette was the first university in the United States to build a solar powered racing boat in 1990-91 and has been participating in races since 1992. The first events for Marquette in 1992 were open competitions in Minneapolis, Seattle and Japan. These were the first competitions in the U.S. but races had been held in Japan since 1989. Mainly companies and inventors participated in the competitions with no other universities except for a few in Japan. The same situation existed in 1993. In 1994, initiated by Marquette through the Solar Energy Division of ASME, the world's first international intercollegiate solar boat regatta was held in Milwaukee, named ***Solar Splash*** and attracted ten universities from the U.S. and Japan. ***Solar Splash*** has been held annually in Milwaukee since 1994 with about sixteen universities now participating in the two-hour endurance races and the 300 m sprints. The rules for the maximum 6 m long boats allow for 480 watts of solar collectors and 1000 watt-hrs of battery storage such that in the two-hour endurance race, approximately 50 percent of the power is from solar directly and the other 50 percent from stored solar energy. Marquette also has continued to race in Japan every year since 1992 and has been the only team from outside of Japan to compete. These competitions have been an exciting interdisciplinary learning experience for the students at a cost much less than other prototype-size solar competitions.

Introduction

Marquette was the first university in the United States to build a solar powered racing boat in 1990-91. This boat was also possibly the first solar powered boat of any type in the U.S. The boat consisted of a canoe, trolling motor, battery, and 200 watts of solar collectors. The boat was tested on Okauchee Lake in April of 1991. Also, about this time, the idea of an intercollegiate solar powered boat race, similar to the solar car races but with international collegiate entries, was presented to the Solar Energy Division of ASME. The idea had also been mentioned to George Ettenheim, President of Advanced Energy Competitions who had organized and produced the 1990 solar car race sponsored by General Motors.

***Sun Warrior,* 1991-92**

In 1991-92, seventeen Marquette engineering students built ***Sun Warrior*** utilizing the hulls from a catamaran racing sailboat and sixteen commercially available solar panels. The boat first raced in Minneapolis, Minnesota. The Minneapolis race was called Minnesolar '92 and was loosely organized as an open competition. There were ten entries including two inventors, nine high schools and Marquette University. Marquette easily won the competition with ***Sun Warrior***.

The boat was then trailered to Spada Lake, near Seattle, Washington where some enthusiasts and companies had been racing electric boats. This was the first year that a solar boat race was held and the race consisted of a four-hour endurance race with no batteries. The heavy ***Sun Warrior*** finished sixth out of seven entries. The boat was also entered in the twelve-hour electric boat race where it finished ninth out of fifteen.

Sun Warrior was disassembled and flown to Japan accompanied by Dr. Reid and nine students. 1991-92 was the year of the ***Grand Solar Challenge*** in Japan and sixty mostly corporate-built solar powered boats were entered in the 100 m sprint and one-hour endurance races held on a lake connected to the Sea of Japan (Mikata-go-ko). ***Sun Warrior*** had been built to the Japanese specifications of 6 m length and 480 watts of solar collectors. All competitors were issued the same batteries. Marquette was, and still is, the only American team ever to race in Japan. ***Sun Warrior*** finished 30th out of the sixty entries. Details of the boat construction and race results have been previously given (Reid and Hoeppner, 1993)[1].

***Sun Warrior II,* 1992-93**

Interest in designing solar racing boats at Marquette grew from one student in fall, 1990, to five in spring, 1991, and then to seventeen students in 1991-92. In the fall of 1992, thirty-two students elected the design and construction of ***Sun Warrior II*** as their number one choice for a senior design project. The electrical engineering, mechanical engineer and industrial engineering students were divided by their choice into Structures, Propulsion, Power Control, Instrumentation, and Simulation subgroups. The objective was to design and build a faster solar powered boat capable of competing in the Minneapolis, Seattle, and Japan races where the differing rules allow from 0 - 200 pounds of batteries and with 0, 40 square feet, and 480 watts of solar collectors. An advantage that this group had over last year's team was the availability of photos and videotapes of all the American and Japanese solar boats of the summer, 1992 competitions. No one other than Marquette faculty and students had seen all of the boats since no other teams raced in more than one race during 1992.

The Structures group visited the Melges Boat Company in Lake Geneva, Wisconsin, to learn about racing boat designs. The Melges Boat Company constructed one of the boats of the America's Cup Race. Two members also attended a short course in composites design at the U.S. Navy-funded Great Lakes Composites Center at Kenosha, Wisconsin. The decision was made to construct a hull from basic materials rather than use an available hull as was done in 1991-92 based on weight-saving opportunities. Because of limitations on equipment needed for composite construction and the small amount of extra weight savings that would be gained by using composites, a foam glass/fiberglass construction method was chosen. After several hundred hours of construction in the lab at Marquette, a fifty-pound hull was fabricated capable

of meeting the solar collector and battery requirements of three races having different rules and requirements. In order to obtain maximum speed, this long, slender boat was designed to carry only the pilot. The Propulsion group defined the characteristics of the propeller needed for the rpm's of the motor as well as designing the steering mechanism. The Simulation group wrote a computer program to predict boat speed as a function of location, weather, and design variables as well as undertaking the management of the construction of the boat during the spring semester. The Power Control Group designed both a flat array and a two-axis sun tracking array, particularly suited for the high latitude of the Seattle race where all boats had a tracking array in 1992. Although 32 students participated in the design and construction, most had graduated and had jobs during the summer so only about ten were available to prepare the boat and participate in racing during summer, 1993.

On June 24, 1993, seven students transported both ***Sun Warrior I*** and ***Sun Warrior II*** to Minneapolis to race both boats in Minnesolar '93. Although the Minnesolar '92 race had entries from two universities and seven high schools along with ***Sun Warrior I***, the 1993 race involved only Marquette University and ten high schools. Carrying 200 pounds of lead acid batteries, ***Sun Warrior II*** crossed the finish line in the sprint race before any other boats reached the two-thirds mark. ***Sun Warrior I*** finished fourth even though a last minute pre-race problem had forced changing to an undersized motor. In the two-hour race, ***Sun Warrior II*** suffered steering problems because of high winds. ***Sun Warrior I***, with the correct motor, won the race. Despite the wind problem, ***Sun Warrior II*** finished in third place.

On July 12, 1993, Dr. Reid and Prof. Hoeppner left for Japan with six students and ***Sun Warrior II***. ***Sun Warrior II*** was quickly reassembled at the Yamaha facilities in Hamanako, Japan, including the fixed array mount appropriate to the lower latitude of Japan and necessary to be able to carry 16 of the 30 watt Solarex photovoltaic panels to give a total of 480 watts, the maximum allowed for the race. Two Panasonic (17 amp-hr [motorcycle]) batteries were supplied by Yamaha for testing, identical to those to be provided at the race.

The next day the group was awed by the viewing of the race site -- the Hamanako Race Boat Stadium. Boat racing is very popular in Japan and betting on the races is also big business. The stadium is somewhat similar to a professional football stadium with closed and open viewing stands, only the race boat stadium is much larger. The rectangular body of water is 580 meters long and 180 meters wide. The enclosed pit area features six elevators to lower the boats from the two-story pit building down into the water.

On the first race day the weather would not cooperate. The twenty corporate-built and four university-built boats waited patiently for the skies to clear but finally the two heats of thirty minutes each were run in a light rain. ***Sun Warrior II*** was the only non-Japanese entry and flew the American flag (Figure 1). Although some solar energy is collected in any type of daylight, most of the energy for this race came from the batteries. ***Sun Warrior II*** finished in the lower half of the heat but had no mechanical or electrical problem. The 30 min. winners were the ***Solar Phoenix 93*** boat entered by Yamaha and the ***Soland*** boat built by Roland Corporation. The rest of the day and most of the next morning were overcast so full recharging of the batteries by the sun (the only allowable method) was difficult.

On Sunday, July 18, the 200 m sprint races were held under mostly cloudy skies. ***Sun Warrior II*** drew Heat 2 of the four heats and finished fourth of six with a time of 1:12.09. Only the first three boats of each heat advanced to two more heats where the final winner was the Yamaha ***Break Now*** solar boat. The one hour race was held as a exhibition only because of the adverse weather conditions. Based on total points, the overall winner was the Roland Corporation ***Soland*** boat which finished first in its 30 min. heat and second in the 200 m sprints. The Yamaha ***Break Now*** team finished second overall. Marquette finished 16 out of 24 in the final standings but, more significantly, finished second out of four among the university teams. The two teams finishing lower were both universities specializing in marine engineering, Tokai University and the Kobe Mercantile Marine University. Kanazawa Institute of Technology finished seventh overall. Also, since solar boat racing started in Japan in 1989, the Japanese remain three years ahead of the United States in solar boat technology.

On July 27, 1993, the team left Milwaukee with the ***Sun Warrior*** trailer and boat driving to the Seattle area to participate in the solar and electric boat races at the Third International Electric Boat Regatta. The races were held on Silver Lake just south of Everett, Washington and were sponsored by GM Delco Electronics and the Snohomish County Public Utility District.

On Saturday, July 31, 1993, the Battery Marathon race was held on the 1.4 mile long course. Each of the fifteen entries was allowed 125 pounds of lead acid batteries for the six-hour race. All entries were from private companies and associations with the exception of Marquette University and Gonzaga University. The solar collectors were removed from ***Sun Warrior II***. The winner of the race was the ***Sea Sabre*** entered by David Mischke of the Seattle Electric Vehicle Association (SEVA). Mischke also built last year's winner of the battery marathon, ***SEVA I,*** which finished fourth in this year's race. The ***Sun Warrior II*** finished seven, an significant improvement over the ninth place finish last year. ***Sun Warrior II***'s average speed was 6.3 mph.

On Sunday, August 1, four boats, including ***Sun Warrior II***, participated in the six-hour long solar boat marathon. No batteries were allowed for this race and only 40 square feet of photovoltaic panels. The solar array for ***Sun Warrior II*** had been converted into a two-axis tracking array using 14 of the Solarex panels instead of the 16 panels used in the flat array in Japan (Figure 2). After four hours of racing, ***Sun Warrior II*** was in second place having completed 16 laps to the leader's 18 laps with a five-lap lead over the third place boat. A gust of wind then capsized ***Sun Warrior II***. The collector array sank but was held to the upside down floating hull by its electrical wiring. After a tow to shore, the bilge pump removed the water and the collector array was mounted back on the boat. All electric systems and the collectors survived the incident. The boat reentered the race for three more laps in the remaining time and still finished two laps ahead of the third place boat after the 75-minute "pit stop." The winning boat was entered by Michael Bittman of UROWN Power Company, a member of the Northern Olympic Peninsula Electric Cars (NOPEC) racing team. The Marquette team received a plaque and $150 for the second place finish.


12
Panasonic Battery

***War Eagle,* 1993-94**

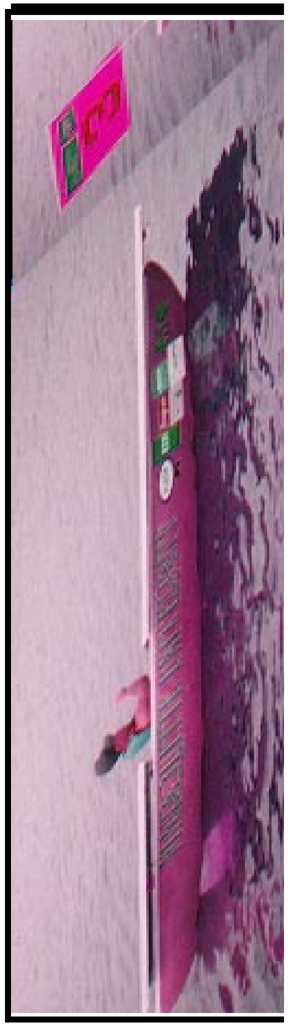
Two years of planning culminated with ASME / Johnson Controls ***Solar Splash '94*** held at the Pewaukee Lake Yacht Club on August 18-21, 1994. As mentioned, discussions about the possibility of such an event had begun in 1990 between Dean Reid and George Ettenheim. Dean Reid, as an ex-Chairman of the Solar Energy Division (SED) of ASME, was appointed to a Student Task Force of the SED in April of 1992. He proposed that the SED provide seed money to AEC to begin planning the event. The SED enthusiastically endorsed the proposed intercollegiate solar boat regatta and the approval process within ASME was begun. After approval by ASME, the cooperation of the IEEE Industrial Electronics Society (IES) was obtained. The race rules were similar to the Japanese competitions. In the fall of 1993, an invitation to participate was sent to all ASME and IEEE student sections as well as to the three Japanese universities who had participated in the ***Hamanako Solar Boat Race*** in 1993. Johnson Controls was secured as the corporate sponsor for the race. Fifteen applications were received including those from the Kanazawa Institute of Technology (KIT), the Kobe University of Mercantile Marine (KUMM), and the University of Puerto Rico. The University of Michigan, winner of the 1990 and 1993 Solar Car Races, and Marquette University were joined by ten other entries from the mainland U.S. universities. Eleven boats from ten universities actually raced including those listed above. The rules were similar to the Japanese rules and allowed the 6 m maximum length boats to carry 480 watts of solar collector and 1000 watt-hrs of battery storage in the two-hour endurance races and 1500 watt-hrs in the 300 m sprints. This gives approximately 50 percent direct solar and 50 percent stored battery energy in the endurance races.

During 1993-94, eighteen mechanical, electrical, and industrial engineering students selected the solar boat project as their senior design project. They were divided into the teams of Structures, Propulsion, Photovoltaic/Battery Systems, and Project Manage- ment/Simulation. The Structures team designed a hull using a boat design software package and decided to construct the hull from carbon fiber. Under the guidance and mostly at the facility of the Great Lakes Composites Consortium (GLCC) in Kenosha, Wisconsin, a wood/foam plug was first made, followed by a fiberglas mold, and finally the carbon fiber and resin were laid in the mold to form the final hull. Individual solar cells were purchased and mounted by a contracted company on material specially selected by the students. A pulse-width modulated H-bridge controller was built and was coupled to either a 3.5 hp (sprint) or 1.25 hp (endurance) motor. A gear reduction, chain-drive system was developed to drive a custom-made propeller. Because of the name change of Marquette University from the ***Warriors*** to the ***Golden Eagles,*** the students christened the new boat, ***War Eagle.***

War Eagle and ***Sun Warrior II*** were both entered in the ***Solar Splash '94*** with ***SUN WARRIOR II*** converted and entered into the tandem class. Unfortunately, there was not time for testing either boat and this led to eventual problems. However, in the 300 m sprint races, ***War Eagle*** recorded the second fastest time for a solar boat. Both Michigan and Arkansas/Little Rock had faster sprint boats but both were strictly electric boats and were not designed to carry solar collectors. ***Sun Warrior II*** had a slow sprint time because of carrying a crew of two. During the two-hour endurance race (Figure 3), ***War Eagle*** developed a drive line problem after qualifying for the championship round. This problem was thought to be

because of prop clutch slippage. The boat also suffered from problems from weeds because of low propeller depth. There was controller problems in both boats which caused ***Sun Warrior II*** to retire in the final endurance race. ***War Eagle*** finished fifth among the solar boats. KIT won both the sprint and endurance races. (Subsequent discussions with KIT revealed that their senior students take no other classes and spend the entire year on their senior project. Also, two graduate students and four professors worked on their design and construction.) Nevertheless, ***War Eagle*** won trophies for Best Motor Design, Best Technical Content of Report, Sportsmanship and Second Place in the Tandem class.

With no time to properly diagnose problems, and with only one day to pack up, the War Eagle team left for Japan to race in the ***Hamanako Solar Boat Race,*** August 27-28, 1994. Twenty-three solar boats were entered including two from Tokai University and one from Osaka University along with Marquette University. (KIT and KUMM were not present because their boats had traveled to the U.S. by ship.) All the other entries were from companies including Yamaha, Honda, Roland Electronics, Kansai Power Company, Sanshin Industries, and others. ***War Eagle*** had been tested and raced at ***Solar Splash '94*** with two small automobile-type batteries but six small batteries with spade connectors were provided in Japan. The current draw of the ***War Eagle*** sprint motor proved to be larger than any available connectors could handle resulting in melting of the connectors. The smaller size endurance motor had to be used resulting in less than optimum performance. Also, the drive line noise persisted and a pin was installed after the sprint race. Several other boats were not even able to complete the sprints. In the one-hour endurance race, the drive line noise still was present and after the race was attributed to chain slippage because of the high power input and high propeller pitch. ***War Eagle*** completed fifty-five minutes of the one-hour race before the chain jumped the sprocket (Figure 4). The overall winner was Roland Electronics followed by Yamaha and Sanshin Industries. ***War Eagle*** received a trophy for international participation because after three years, Marquette has been the only entry from outside of Japan. ***War Eagle*** still finished ahead of four companies and one Japanese university.



9R 2 3 4 5 6

Solar Eagle* and *Mirage, 1994-95

In preparation for ***Solar Splash '95***, the team of senior engineering students designed and constructed two solar powered boats, ***Solar Eagle*** and ***Mirage***. With technical assistance and funds from Fleck Controls, the ***Solar Eagle*** hull was fabricated in Massachusetts in an advanced process using aluminum honeycomb sandwiched between layers of carbonfiber. This gave a light hull that is also very strong. The ***Mirage*** hull was made inexpensively by gluing together four-inch thick slabs of polystyrene building insulation, cutting the hull shape with a hot wire, and then covering the shape with one layer of fiberglass. The interior was carved out as would have been done by primitive people making dugout canoes. This hull was then extremely light and of moderate strength. ***Solar Eagle*** used a flexible drive shaft designed jointly by Marquette students and Fleck engineers while ***Mirage*** used a student-designed bevel gear drive train machined at an outside shop. Complete technical details of the design have been previously reported (Reid and Hoeppner, 1996)[2].

Because of limited capacity for spectators at the Pewaukee Lake site, a new site was chosen for ***Solar Splash '95***. The City of Milwaukee has festival grounds adjacent to the downtown area on the Lake Michigan shoreline. Inside the breakwater is a man-made island separated from the festival grounds by a lagoon with relatively calm waters. Although nearly all of the ethnic festivals held on the site during the summer have water events in the lagoon, the Polish festival did not have such an event so ***Solar Splash '95*** was held in conjunction with ***PolishFest '95***.

Complete details of the race have already been given (Reid and Hoeppner, 1996). ***Mirage*** finished in third place among the sixteen entries behind KIT and a combined team from Artisan College/University of Southern Maine. ***Solar Eagle*** finished fourth. In the endurance race, ***Mirage*** had electrical problems and did not start but ***Solar Eagle*** finished fifth. Arkansas/Little Rock and the University of Michigan who had built only sprint boats finished first and third, respectively, while KIT finished second and Artisan/Southern Maine was fourth.

Because of the success of the very light weight foam hull of ***Mirage***, another foam boat was constructed before the trip to Japan and christened ***Mirage II***. Unfortunately, at the Hamanako Solar Boat Races on July 29-30, 1995, a control malfunction caused ***Mirage II*** to capsize at the start of the sprint race. The electrical systems were damaged beyond control and no points were obtained. The controller was repaired that evening but failed to function at the start of the endurance races the next day. After a fifteen-minute delay, the boat started and finished the race but officially received a did-not start. Based on lap time, ***Mirage II*** might have finished sixth.

***Solar Storm*, 1995-96**

The first race of 1996 was at ***Solar Splash '96***, held in Lake Michigan at ***Polish Fest***, June 20 - 23, 1996. There were sixteen entries including Marquette's ***Solar Storm*** and a combined entry from Marquette University and the University of Minnesota christened

Solar Flare. ***Solar Storm*** was constructed using the ***Mirage II*** hull, the boat that was built after ***Solar Splash '95. Mirage II*** was taken to Japan but capsized in the sprints disabling the electrical system for the remainder of the '95 Hamanako solar boat races. The hull was extensively reworked during the 1995-96 academic year. This included lowering the height by 3 inches, lightening the boat considerably, and smoothening the outside surfaces before repainting. The bevel gear endurance drive train was disassembled and new bearings installed but the same design was used. However, an entirely new sprint drive train was designed and constructed and, for the first time, a Marquette solar boat had a counter-rotating propeller system. Both propellers were on the aft part of the shaft but rotating in opposite directions. One propeller had two blades and the other had three blades. The solar collectors were reused for the third straight year but an improved mounting system of reinforced foam was constructed. The complete design details are available elsewhere (Reid, Schreihart, Hoeppner, and Schabelski, 1997)[3].

The University of Minnesota (UMN) had constructed several human-powered hydrofoils during the past three years so a marriage of the Minnesota hydrofoil capabilities and the Marquette solar power experience seemed to provide an opportunity to construct the first U.S. solar powered hydrofoil. This design had been first used by Yamaha in winning the 1992 race in Japan and also by several other teams in Japan since 1994. Kanazawa Institute of Technology (KIT) used a hydrofoil in ***Solar Splash '95*** but no U.S. team had been successful with this very difficult design. A senior design group in the mechanical engineering department at UMN worked with the Marquette team, primarily by e-mail and by posting drawings and information on the Marquette Solar Energy Society home page on the World Wide Web. Unfortunately, the UMN team did not arrive in Milwaukee until 3:00 a.m. on Thursday, June 20. Much work remained to be done in the one day before the qualifying deadline for ***Solar Splash '96***. Most components were installed on the boat but with no testing time available, ***Solar Flare*** was unable to qualify for the race.

Solar Storm was leading the two-hour endurance race during ***Solar Splash*** but snagged a lost buoy rope with twenty minutes remaining in the race. Although the rope was quickly removed at the dock, the University of Massachusetts-Dartmouth had taken the lead and although gaining, ***Solar Storm*** crossed the finish line twenty-five meters behind UMASS (Figure 5). Again, electrical problems developed in the sprints and ***Solar Storm*** received a did-not-start. The problem was later traced to a faulty connector. The University of Michigan boat won the sprint. For the first time, a total point system was used and although KIT did not win either of the main events, they were the overall champion of ***Solar Splash '96***.

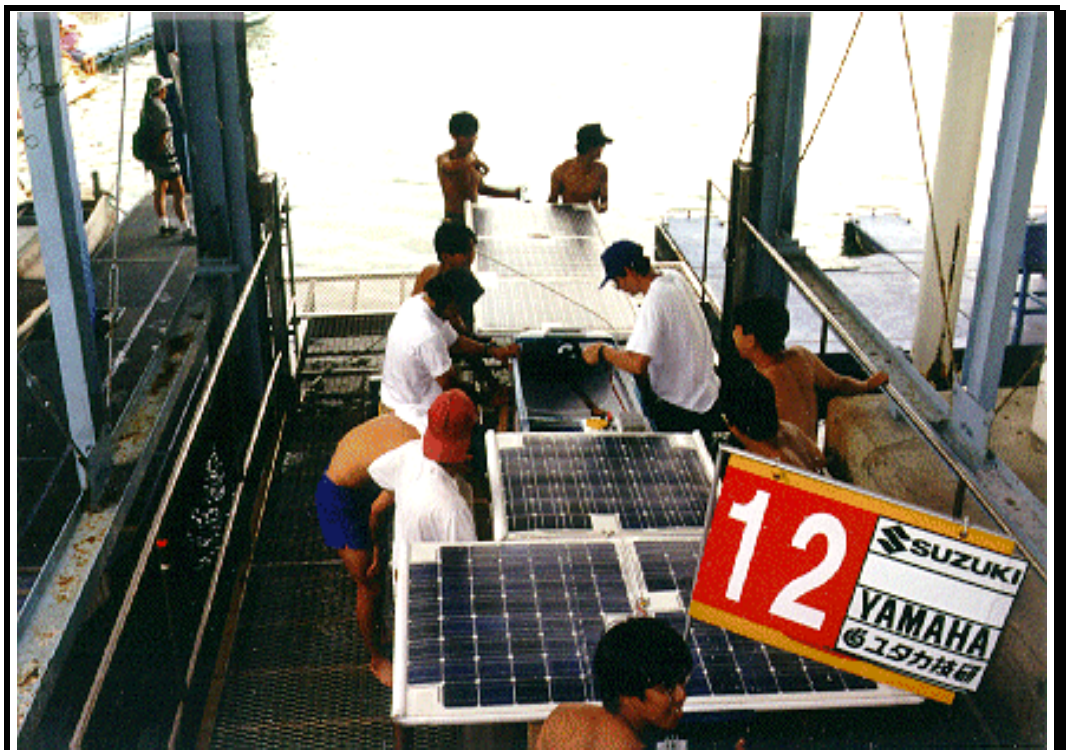
At the 1996 Hamanako Solar Boat Races, there were four universities in the sixteen-boat field. KIT and Tokai University were entered along with Marquette (Figure 6) and a new entry from Osaka University. Because of a wind gust, ***Solar Storm*** listed and part of the aft collector array was dislodged into the water and was drug across the finish line. The controller had been thoroughly tested in wet conditions but not in salt water as is present in the Hamanako racing boat stadium. The splashing salt water ruined the controller such that a less efficient backup controller and motor had to be used for the endurance race the next day. Overall, Marquette finished tenth in the competition won by Roland Corporation.

Solar Storm

Conclusion

The ***Solar Splash*** solar boat race is an excellent competition where college students can participate in an alternative energy event at far less cost than the solar car races. Other entries not mentioned earlier that show the diversity of the competition have been Columbia University, the University of California at Santa Barbara, the University of New Orleans, the University of Wyoming, Grand Valley State, the University of Maine, Oral Roberts, and the U.S. Coast Guard Academy.

Most of the universities have designed and built their solar powered boats as a senior design project. At Marquette, this ideally fits our interdisciplinary senior design project requirement and mechanical engineers, electrical engineers, and industrial engineers have teamed on the project. Engineering students below the senior level and from other curricula both inside and outside of engineering have participated through the Marquette Solar Energy Society. ***Solar Splash '97*** will be held at the same location in Milwaukee on June 19-22, 1997.



References

[1]Reid, R.L. and Hoeppner, B.D., "Sun Warrior: First U.S. Collegiate Solar Powered Racing Boat," Proceedings of the ASEE Centennial Annual Conference, University of Illinois, June 20-24, 1993, pp. 869-873.

[2]Reid, R.L. and Hoeppner, B.D., "Marquette University's Solar Eagle/Mirage Solar Powered Racing

Boats," ***Solar Engineering - 1996***, Proceedings of the 1996 ASME Solar Energy Conference, San Antonio, March 31 - April 3, 1996, pp. 207-213.

[3]Reid, R.L., Schreihart, L.M., Hoeppner, B.D., and Schabelski, J.P., "Marquette University's ***Solar Storm*** Solar Powered Racing Boat," ***Solar Engineering - 1997***, Proceedings of the ASME International Solar Energy Conference, April 27-30, 1997.

Biographical

ROBERT L. REID. Dr. Reid has been Dean of the College of Engineering at Marquette University since 1987. He is a former chairman of the Solar Energy Division of ASME and is the technical editor of the ***ASME Journal of Solar Energy Engineering***. He is a Fellow of ASME and in April, 1997, he received the ASME John I. Yellott Award for outstanding accomplishments in the field of solar energy engineering.

BRUCE D. HOEPPNER. Prof. Hoeppner is the Computer Systems Manager at Marquette University and was formerly the director of undergraduate laboratories for the Department of Electrical and Computer Engineering. He graduated from Marquette University in 1982 and earned his masters in 1985. Prof. Hoeppner worked for the U.S. Air Force in electronic warfare systems, specifically in radar warning simulation and testing.