Broader Perspectives

EVENT REPORT

Sunrayce 93: Collegiate Competition Introduces American Public to Photovoltaics

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Thirty-four university teams raced their solar-powered cars from Texas to Minnesota during the week of the summer solstice, 20–26 June 1993. The event, called Sunrayce 93, was a dazzling display of creativity and ingenuity by some of the brightest students in North America. Organized by the United States Department of Energy as an educational programme for college-level science and engineering students, the race also serves to introduce the public to photovoltaics, electric vehicles and energy efficiency.

THE RACE

The outcome of Sunrayce 93 was decided on 24 June 1993, the fifth day of the 7-day cross-country event for solar-powered cars, as 34 teams struggled to reach the finish line in Des Moines, Iowa. The cars were designed, built, tested and raced by students enrolled at colleges and universities from all across North America. Each car had proved its ability to combat heavy traffic, hills, potholes and railroad crossings. But five straight days of cloudy weather proved to be too much for most of these cars, which rely solely on the sun for propulsion.

Thirty-four teams left the starting line heading north from Arlington, Texas, located just west of Dallas (Figure 1). Twenty of the cars completed the full 264-km distance on day 1, but only nine made the 248-km distance on day 2. Eleven made it 315 km on day 3 to Tulsa, Oklahoma, but only six could finish the 254-km segment on day 4. With only 30 min left for racing on day 5, not one car had covered the 262 km needed to reach the finish line in Des Moines. In this last 30 min, just two cars would cross the finish, making day 5 the decisive day of the race.

The car from Iowa State University (ISU) crossed the line first on day 5, much to the delight of the partisan local crowd. But ISU had started the day in tenth place and was never within reach of the leaders. The University of Michigan had started day 5 in second place, 10 min behind the California State Polytechnic University at Pomona. But when Michigan crossed the finish line in Des Moines with just 13 min remaining in the race day, they grabbed a commanding lead of almost 2 h. Sunny skies for the last 2 days of the race made it nearly impossible for any other team to overcome Michigan's lead. Twenty-one cars finished the 283-km distance on day 6, and all 34 cars finished the final leg of 146 km to cross the finish line just south of Minneapolis, Minnesota. Despite a flat tyre less than 1 km from the finish line, Michigan's car, the *Maize and Blue*, finished the race with a 90-min lead. A listing of the final standings is given in Table I (see Appendix). Figure 2 illustrates how the rankings of the top four teams evolved during the race. Photographs of these four teams are shown in the Appendix.

THE EVENT

Sunrayce 93 was organized by Richard King of the Photovoltaics Technology Division of the United States Department of Energy (DOE), to provide an exciting and challenging opportunity for college and university students to develop hands-on engineering skills, while at the same time promoting renewable energy and

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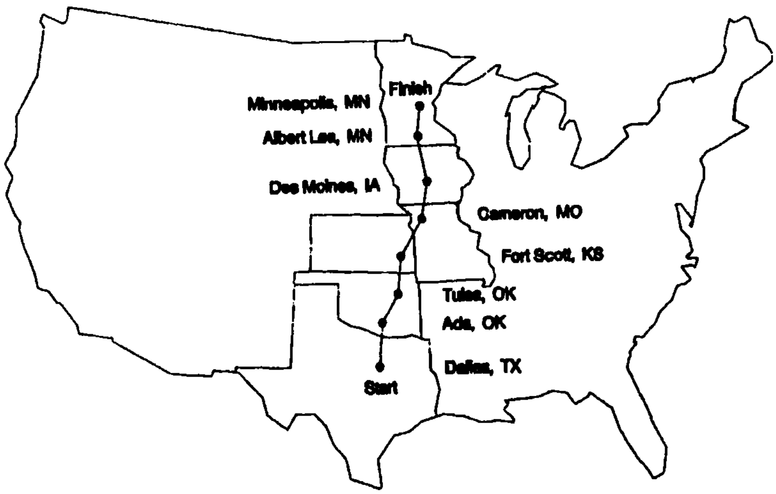

Figure 1. The route of Sunrayce 93

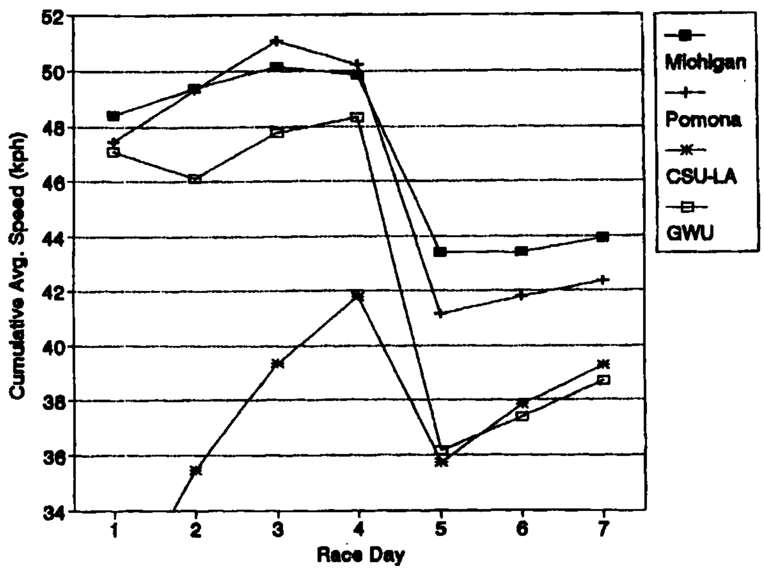

Figure 2. Cumulative average speed of the top four finishers on a day-to-day basis

energy efficiency. The race is planned to be held every 2 years. Cécile Leboeuf at the National Renewable Energy Laboratory (NREL) managed the 1993 event, coordinating the activities of a hundred race officials from various governmental and industrial sponsors. Major financial support for the race was provided by the DOE and the General Motors Corporation.

Teams were selected for Sunrayce 93 through a competitive proposal process open to all colleges and universities in North America. Students were not only required to demonstrate technical competence, but also to plan for fund raising and to integrate their project into the university curriculum. Thirty-six teams were chosen for the race, although two subsequently withdrew. Teams raised funds from their schools, alumni and industrial sponsors to support the development, testing and racing of their cars. Budgets ranged widely, from as little as \$50 000 to over \$500 000. Most of the teams were groups of engineering students, although several teams included students from other disciplines, such as meteorology, business, journalism and nutrition. For most of the students involved in Sunrayce, the solar-car project was the single most significant event of their collegiate education, both in terms of commitment and personal reward.

Sunrayce 93 is a rally event, in which the overall winner is determined by summing the times required to finish each leg for the 7 days of the race. The advantage of this format is that it brings all of the teams together in one place at the end of each race day. The cars leave the starting line each morning starting at 9 a.m. local time, at 1-min intervals. For safety reasons, each team is required to protect their solar car on the highway with a steel-bodied vehicle in front and a full-sized van behind. If a team fails to reach the finish line before 6:30 p.m. local time, they must load their car onto a trailer and transport it to the finish line. A team is penalized 4 min for every mile that they have to trailer their car. Penalties are also assessed for replacement of storage batteries and for traffic violations. The total elapsed timed and average speeds listed in Table I include the effect of these penalties.

Sunrayce 93 instituted regional qualifiers, requiring each team to prove, before the race, that their car could go at least 80 km under its own power in less than 2.5 h. There were three qualifiers: an Eastern qualifier at the Indianapolis Motor Speedway, a Western qualifier at the Phoenix International Raceway and a Final qualifier 1 week before the race for teams that failed to qualify at one of the two regional events. The combination of scrutineering and qualifiers was instrumental in improving the safety of the race; there were only three minor incidents involving the solar cars. Large trucks passing at high speed blew the driver canopy off one car and blew another car completely off the road. A third solar car was rear-ended by its own chase vehicle. Damage in all three cases was minor, and nobody was hurt.

A complete technical report on Sunrayce 93 is scheduled for release by the DOE later this year. It will follow a similar format to the technical report prepared for the 1990 World Solar Challenge solar-car race across Australia.[1] Information about the 1990 GM Sunrayce USA, on which Sunrayce 93 was patterned, was published as a special issue of the journal *Solar Cells.*[2]

THE CARS

Vehicles entered in Sunrayce 93 had to satisfy a variety of design and performance criteria intended to ensure a safe, fair race in which solar energy derived directly from the sun is the sole source of propulsion. All of the cars in Sunrayce 93 used photovoltaic cells as their energy source; these will be discussed in detail in the next section. The cars were permitted to carry up to 5 kWh of batteries for energy storage. Only commercially available lead–acid batteries were permitted. The entire car had to be less than 6 m long and 2 m wide. The car had to be at least 1 m tall so that it could be seen by other traffic. Teams had to demonstrate, by detailed calculation or by direct testing, that the vehicle was able to protect the driver in the event of an impact from the side, front or rear, or from a roll-over. The car had to have a certain turning radius for manoeuvrability, good visibility for its driver and be equipped with adequate brakes, signals and horn.

All of the cars were made of lightweight materials. Most cars used a space frame of tubular aluminium or titanium, with an outer body of honeycomb composites. For some cars the entire structure was made of composite material, most often graphite–epoxy. After loading about 75 kg of lead–acid batteries on board, the cars weighed between 300 and 500 kg. Competitive cars were equipped with brushless high-efficiency electric motors for propulsion and were designed with careful attention to minimizing aerodynamic drag and rolling resistance. Typical power consumption is about 2 kW at 60 k.p.h. Low rolling resistance requires thin, high-pressure tyres; consequently, flat tyres were quite common during the race and a good team could change a tyre in just a few minutes.

There were three basic shapes for the cars entered in Sunrayce 93. The most common shape was a low, thin vehicle having minimal cross-sectional area both from the front and the side. Two variants on this approach were a flat bottom with a curved top surface, or a flat top surface with a curved bottom. The second most common shape was a missile-like pod for the driver, with a separate planar sheet for the photovoltaic array. The sheet could be fixed in the horizontal plane or have adjustable tilt to track the sun. The third shape had an inverted-U frontal cross-section. This shape had increased exposure to side winds, but also more area on its sides for photovoltaic cells. The winning car was of the third type, the second-place car was of the second type and the third- and fourth-place cars were of the first type.

The cars were inspected thoroughly prior to each qualifier and before the main event by a team of professionals to ensure that they complied with all regulations related to safety and fairness, a process known as 'scrutineering'. In addition to direct inspection of the vehicles, scrutineering included a handling test, in which the cars had to weave through a slalom course at 25 k.p.h., and a braking test, in which cars had to stop from 40 k.p.h. with a deceleration of at least 4.2 m s^{-2}. The car with the best brakes, from the University of Missouri, was able to stop at 8.7 m s^{-2}.

THE PHOTOVOLTAIC ARRAYS

Race rules for Sunrayce 93 required teams to use only terrestrial-grade photovoltaic solar cells. The cells had to be available to all entrants at a cost not exceeding \$10 W^{-1}. Nine of the top 10 finishers used laser-grooved buried-contact monocrystalline silicon cells manufactured by BP Solar. Testing of these cells at Sandia National Laboratories prior to the race indicated that they had an average efficiency of about 16% under standard test conditions. The University of Maryland finished sixth using multicrystalline silicon cells from Solarex Corporation. Other teams used crystalline silicon cells from Siemens Solar Industries, AstroPower, Kyocera and Solec.

The photovoltaic array, including any reflectors, could be configured in any arrangement provided that at all times it fitted within an imaginary box of limited size. The length of the imaginary box could not exceed 4.4 m, the width could not exceed 2 m and the height could not exceed 1.6 m. Furthermore, the product of the length and width could not exceed 8 m^2. Whenever the car was racing, the imaginary box enclosing the array had to be oriented parallel to the ground. But the array could be removed from the car and propped up to face the sun when the car was stationary, in which case the imaginary box could be repositioned to any orientation. All of the cells had to be visible from the outside of the car at all times. This prevented teams from pursuing a strategy of collapsing the array into the vehicle to reduce aerodynamic drag during racing and then unfolding the array for charging. It would confuse the public to see 'solar' cars racing down the road with no visible means of solar energy conversion.

It is important to understand that the constraint on the array is based on volume, not area. The teams that used an inverted-U vehicle design had significantly more cell area than the other teams. Under sunny skies, the inverted-U shape ensures that a substantial number of cells are facing towards the sun even when the sun is near the horizon to the car's left or right. Another benefit of this design occurs on hazy days, when the diffuse light produces power in every cell, regardless of its orientation.

The volumetric constraint was also used to great advantage by six teams who realized that they could significantly reconfigure their array when they were stopped for charging. Figure 3 shows how an array that normally presents a cross-section of 8 m^2 in normal racing position can be reconfigured to fit across the diagonal of the imaginary box, thus providing an illuminated area of 10.2 m^2 for charging. The additional cells were carried on the lower sides of the array structure during racing, fulfilling the requirement that the entire array be visible from the outside of the vehicle. Three of these six teams received awards for innovative design of their solar array; first place went to The George

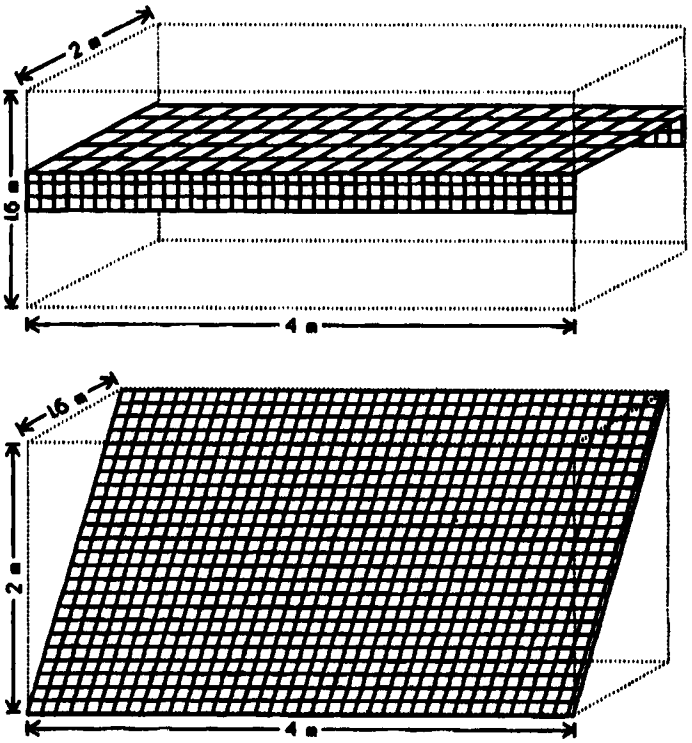

Figure 3. The solar array must fit into an imaginary box of specified size. The top diagram illustrates an array in racing position and the bottom diagram illustrates how this same array can be reconfigured for charging

Washington University for exceptional array workmanship, second place to the University of Maryland for exceptional performance using a multicrystalline array and third place to Rose-Hulman Institute for designing the solar array to interface to the vehicle with minimum electronic complexity.

THE PUBLIC

Sunrayce 93 generated a lot of interest from both print and broadcast media. The start of the race in Fort Scott was carried live on the CBS television network, short clips from the race were shown on the Cable News Network and a crew from *Scientific American* filmed the race for a show to be aired the first week of December 1993 on the Public Broadcasting System. While this national exposure is important to the sponsors of the race, the real impact of Sunrayce 93 was in the communities along the race route and at the colleges and universities entered in the competition. The race was front-page news in every city and town through which the cars travelled. The response was particularly impressive in the smaller towns like Ada, Fort Scott, Cameron, Ames and Albert Lea. Mandatory 15-min midday stops were staged in towns along the race route, giving the public a chance to see the cars first-hand. As many as a thousand people flocked to each of these stops.

But what was the effect of this publicity on the public's perception of photovoltaics as an environmentally benign energy source or electric vehicles as energy-efficient transportation? An editorial written by the Tulsa World newspaper on 1 July 1993 congratulates the students for their engineering achievement, but uses the slow speed of the cars in the race as proof that 'this competition and others like it demonstrate more than anything else that the internal combustion engine will remain the only practical automotive power for the foreseeable future'. Admittedly, this view comes from the heart of oil and gas country, but it does reflect the challenge that new technology faces when it is presented to the public in a highly visible forum.

Photovoltaics is used in Sunrayce to give each team a limited energy resource with which to compete. The primary emphasis is really on energy efficiency. Because the energy available to each car is barely enough to complete the task, and the cost of ultrahigh-efficiency components is high, the public perception of photovoltaics and electric vehicles can be distorted. To combat this perception, booths were set up along the race route by the Solar Energy Industries Association, the DOE and the Environmental Protection Agency to distribute information describing practical, cost-effective applications of renewable energy and energy efficiency.

It does make technical and economic sense to put photovoltaics on vehicles in certain situations. Photovoltaics can be the sole energy source when the vehicle is used only infrequently, for short distances. Photovoltaics may pay for itself on electric commuter cars by lengthening the life of the batteries.[3] Photovoltaics can also be used on gasoline-powered cars, to run ventilation fans to cool the interior on sunny days. But photovoltaic power for an electric car would most likely be implemented as a fixed installation, not on the roof of the vehicle. Regional races in New England, California and Florida have evolved that feature practical, cost-effective electric vehicles, some of which are charged from photovoltaics.

Sunrayce 93 introduced the public to photovoltaics. It allowed them to see photovoltaics being used by enthusiastic college students in an exciting context. Some may have gone away with a perception that photovoltaics is weak and expensive. But far more important are the thousands of people who saw photovoltaics not in terms of its limitations but as an opportunity for the future.

APPENDIX

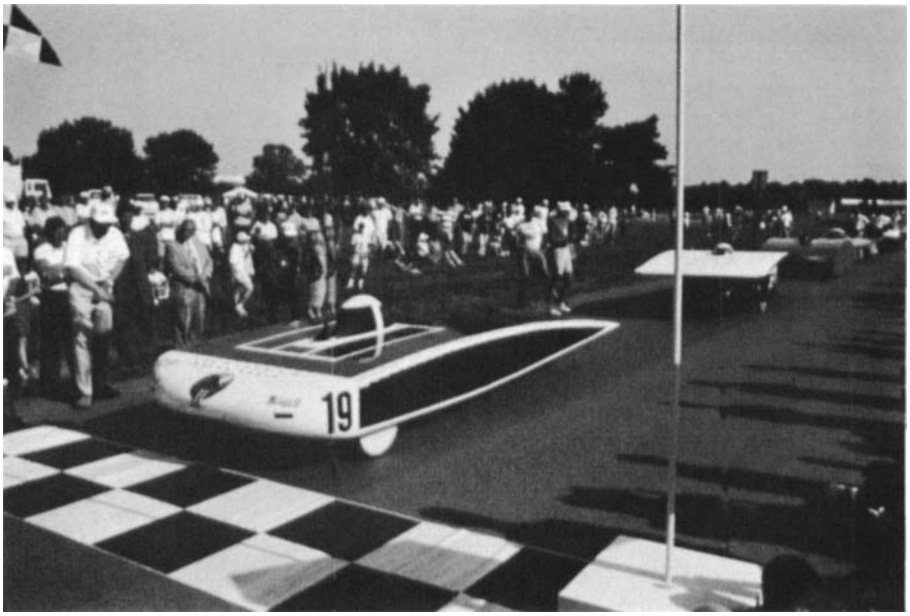

Figure 4. First Place: The University of Michigan
Name: *Maize and Blue*
Team Captain: Furqan Nazeeri
Advisors: Dr Bruce Karnopp, Dr Gene Smith

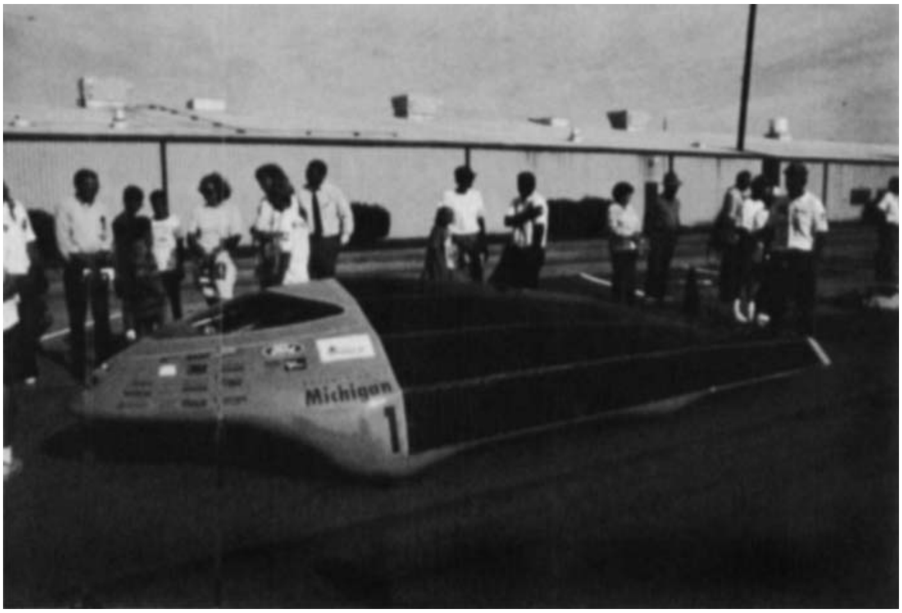

Figure 5. Second Place: California State Polytechnic University at Pomona
Name: *Intrepid*
Team Captains: Alan Redmond, Wayne Watson, Tina Shelton
Advisors: Dr Michael T. Shelton, Don VandeGriff, Gerald Herder

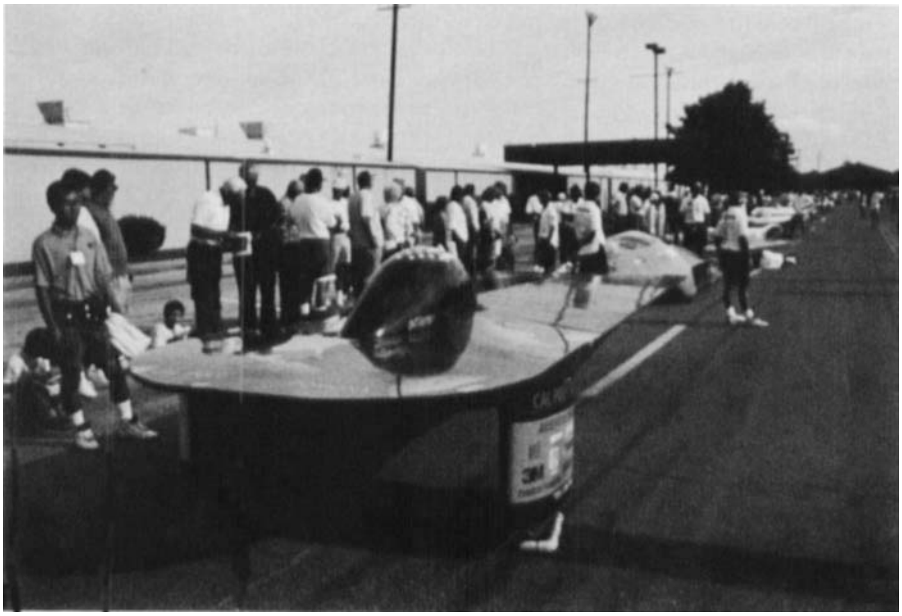

Figure 6. Third Place: California State University at Los Angeles
Name: *Solar Eagle II*
Team Captain: Ricardo Espinosa
Advisor: Richard Roberto

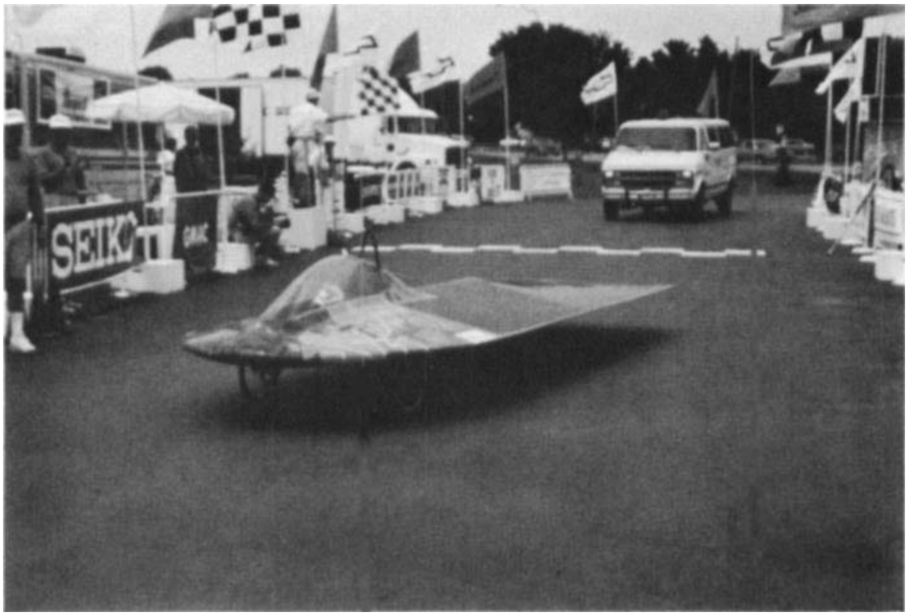

Figure 7. Fourth Place: The George Washington University
Name: *Sunforce 1*
Team Captains: Barrett Crane, Rob Piacesi, Cory Knudtson
Advisors: Dr Nabih Bedewi, Joel Jermakian

Table I. Sunrayce 93 final standings

Position	Team	Time (hh:mm:ss)	Speed (k.p.h.)
1	University of Michigan	40:39:18	43.9
2	California State Polytechnic University, Pomona	42:09:20	42.4
3	California State University, Los Angeles	45:26:58	39.3
4	The George Washington University	46:06:55	38.7
5	Stanford University	52:48:46	33.8
6	University of Maryland	55:42:30	32.1
7	University of Oklahoma	64:18:36	27.8
8	University of Massachusetts, Lowell	66:39:20	26.8
9	Kauai Community College	68:52:39	25.9
10	Iowa State University	70:17:42	25.4
11	McGill University	70:34:35	25.3
12	California State University, Fresno	75:30:23	23.6
13	Arizona State University	78:04:24	22.9
14	Queens University	78:14:48	22.8
15	Rose-Hulman Institute of Technology	79:41:30	22.4
16	Mankato State University	79:52:53	22.4
17	Drexel University	81:04:11	22.0
18	Western Michigan University	81:09:32	22.0
19	University of Missouri, Columbia	82:57:17	21.5
20	Virginia Polytechnic University	85:14:13	21.0
21	University of Minnesota	85:17:23	20.9
22	Rochester Institute of Technology	85:45:47	20.8
23	Stark Technical College	86:02:02	20.8
24	Colorado State University	87:02:00	20.5
25	Auburn University	90:04:22	19.8
26	University of Ottawa	90:19:11	19.8
27	University of Puerto Rico	91:06:11	19.6
28	Clarkson University	91:51:14	19.4
29	University of Missouri, Rolla	96:07:16	18.6
30	Mercer University	96:17:15	18.5
31	University of California, Berkeley	98:25:46	18.1
32	University of Texas, Austin	101:59:37	17.5
33	University of Waterloo	108:09:18	16.5
34	New Mexico Institute of Mining and Technology	117:48:11	15.2

REFERENCES

1. C. R. Kyle, *Racing with the Sun; The 1990 World Solar Challenge*, Society of Automotive Engineers, Warrendale, PA, 1991.
2. R. J. King, 'Solar cars race for the future: results of the GM Sunrayce USA and the World Solar Challenge', *Sol. Cells*, **31** (1991).
3. W. E. Rippel, *Viability Study of Photovoltaic Systems added to Terrestrial Electric Vechicles*, Jet Propulsion Laboratory Report JPL D-7824, Pasadena, CA, September 1990.