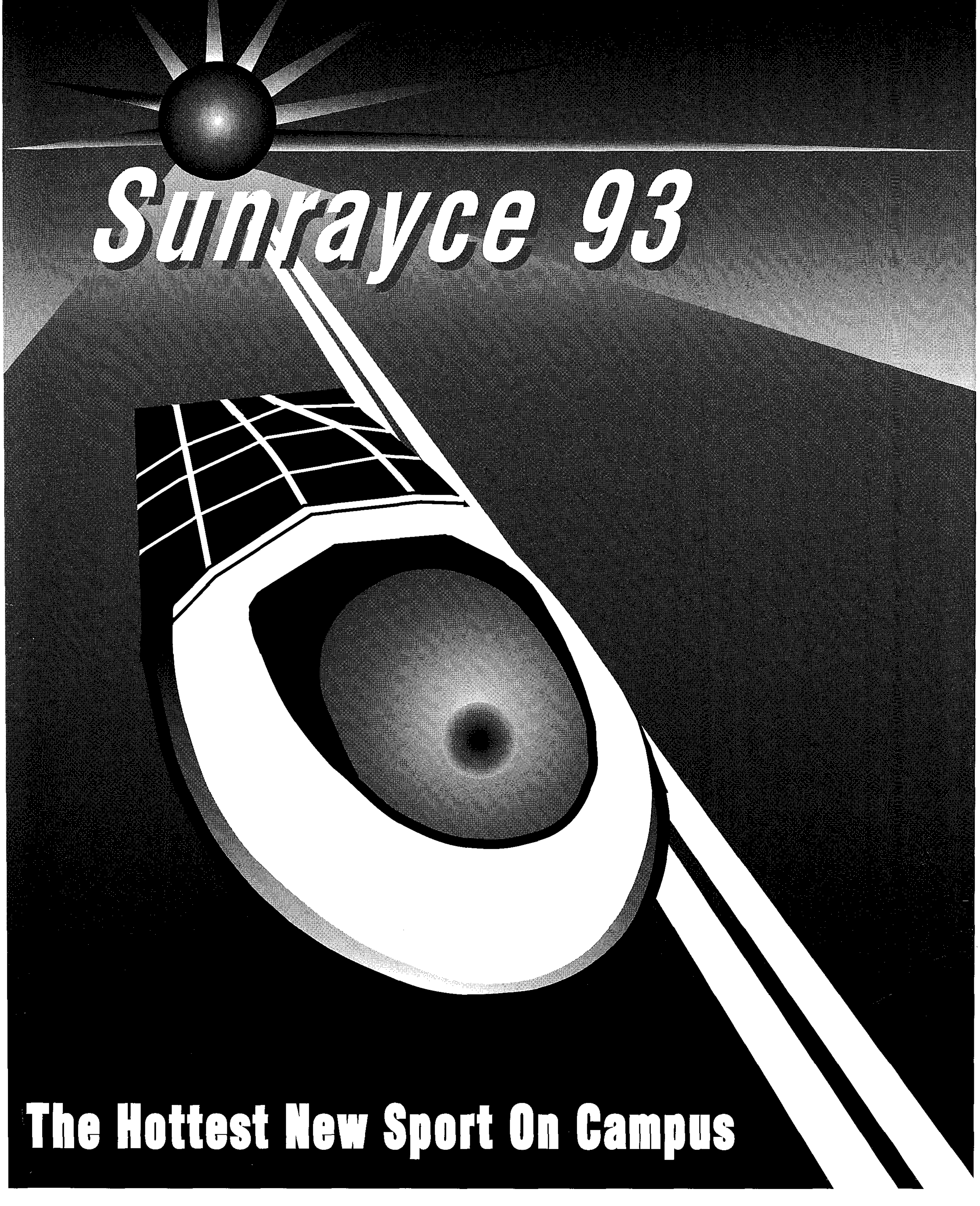
Technical Report

Sunrayce 93



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May 1994 • NREL/TP-411-6767

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Available from:
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

Price: Microfiche A01, Printed Copy A03

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1617 Cole Boulevard
Golden, Colorado 80401-3393
A national laboratory of the U.S. Department of Energy
Operated by Midwest Research Institute
for the U.S. Department of Energy
Under Contract No. DE-AC02-83CH10093

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The U.S. Department of Energy (DOE) is proud to be the lead sponsor of Sunrayce 93. The DOE designated the National Renewable Energy Laboratory (NREL), the nation's leading laboratory for renewable energy research, to manage Sunrayce 93. Along with the Department of Energy, there are several enthusiastic sponsors who contributed to the success of this event. Foremost among them is General Motors Corporation

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Acknowledgments

Sunrayce 93 was the culmination of a two-year educational program for college level science and engineering students. Approximately fifty students from each of the 36 participating universities formed a team to design, build and race their solar powered car. Over 1800 students were directly involved in Sunrayce 93. This technical report documents their place in history and provides the foundation on which the next generation of students can build.

Our sincere thanks to all who made this report possible. We are especially grateful to Joyce Kyle, who wrote Chapter Four and took most of the photos. We thank her for capturing the stories and background that made the race special for so many people. We wish to thank Susan Fancy, Paul Basore, Howard Wilson, Erik Nelsen and Richard King for their time they spent editing the manuscript. And thank you also to the American Solar Energy Society for their work in coordinating the prodcution of this report.

Finally, we wish to thank all the sponsors who contributed their time and resources to make the event a success, especially the U.S. Department of Energy.

Sunrayce 93

DOE • GM • SAE • NREL

Technical Report

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Introduction

Back in 1838, when the first electric car was built, no one imagined that such cars might one day be charged by the sun's rays alone. Who would have dreamed that some day we would be cruising along at highway speeds on sunpower? Ironically, Charles Fritts and Edmond Becquerel's seminal work in photovoltaics occurred only one year later, in 1839, when they invented the first selenium solar panel. These two developments occurred separately, and what could have become a dramatic opportunity for collaborative work resulted instead in distinctly divergent paths. The possible link between photovoltaics and electric vehicles was not recognized until nearly 150 years later.

Electric cars were quite common in the early 1900s. The internal combustion engine was regarded as dirty, noisy, and fairly unreliable, with the result that, at the turn of the century, 38% of all privately-owned cars in the U.S. were electric vehicles. Electric-powered taxis, milk trucks, and trolley cars were a familiar sight through the 1930s. But the limited range of these vehicles and a shortage of electric power sources outside city boundaries combined to seal the fate of early electric automobiles.

From the 1940s to the 1970s, electric vehicles were more often seen at museum exhibitions than on the road. Oil was plentiful and economic growth in the United States sped forward at a lightning pace. Expressions of concern about the earth's dwindling resources went unheeded, as did environmentalists' warnings about the state of the biosphere. Then, without warning, the oil crises of the seventies brought energy issues into sharp focus. Suddenly, both scientists and politicians saw their perspectives turned upside down, as leaders all over the world scrambled for solutions.

One lesson we can draw from natural history is that change takes time. In the grand scheme of things, evolutionary change rather than revolutionary change predominates on our planet. Adaptations for survival among species of plants and animals proceed gradually, with Mother Nature oblivious to the demands of any intrusive time structure.

But humans DO have the unique capacity to impose their will on the natural world. Indeed, successful leadership in a human community often falls to those who refuse to be dominated, so that they themselves might become the dominant forces of change.

In fact, the visionaries who dare to challenge the status quo often provide the most inspirational leadership. Who were the bold entrepreneurs determined to make a difference in our plans for an energy-bright future? Why did they choose "the road not taken" in pursuit of their dreams?

Paul MacCready was one of the first to emerge as a leader in solar-powered transportation. Never content to accept "what is," this mastermind of aerodynamic engineering and human-powered flight is well-known for tackling "what can be." In 1981, MacCready built a solar-powered airplane, the Solar Challenger, and flew it across the English Channel. With over 16,000 solar cells mounted on the wings producing 3000 watts of power, this incredible flying machine proved to be reliably strong in flight. The Solar Challenger crossed the English Channel in five hours and 23 minutes and demonstrated that by stretching the limits of technology, humans can make quantum leaps.

MacCready recognized that this project was more "a symbol and a stimulus" than a realistic alternative for everyday flying. If he could focus more attention on solar energy, then maybe he would help push the technology forward. As it turns out, his 1981 accomplishment with solar-powered flight did make a difference. Unbeknownst to MacCready, news of the Solar Challenger was a key inspiration for two individuals living and working oceans away.

Hans Tholstrup is one of those individuals. A man of ceaseless energy, Tholstrup is committed to an activist approach to the energy crisis. Not content to sit back while others brainstormed possible solutions to any problem, Tholstrup insisted upon setting examples. After reading an article about MacCready's solar airplane, the bold Australian adventurer decided to build a solar-powered car. If someone else could fly on sunpower, then he could drive on it. In 1982, Tholstrup drove his solar car across the Australian continent, a remarkable feat that revolutionized our view of transportation.

A few years later, Tholstrup created a cross-country race for solar-powered cars. Called the World Solar Challenge, it stretched over 3000 kilometers (1864 miles) from Darwin to Adelaide. Ironically, Paul MacCready was instrumental in designing the solar car that won the race. And so it is that one historical event led to the birth of another, sparked by the ever-ingenious human spirit.

On a third continent, the plans of yet another young scientist were brewing. A 26-year-old Swiss electronics engineer named Urs Muntwyler was looking for a way to educate the public about the benefits and potential of solar electric power. During a late-night brainstorming session with some friends in September 1984, Muntwyler had an idea. At the time, the idea seemed both radical and brilliant.

Muntwyler knew of Paul MacCready's accomplishments, and was inspired by his aerodynamic wizardry. In fact, he had used MacCready's calculations and sailplane models on several occasions. After the Solar Challenger made its successful flight over the English Channel, Muntwyler pored over the articles about this unique solar aircraft. He claims that MacCready's accomplishments made a substantial impact on his own thinking and achievements.

While working for a small photovoltaics firm in Switzerland, Muntwyler was asked to help the marketing department increase the company's visibility. At first, he thought a large demonstration of photovoltaic power might be the answer, but he realized the limits of having a stationary display. Next, he considered loading a PV system onto a trailer and driving it around to show people. The more he thought about it, the more he liked the idea of a parade, which led to the concept of driving solar electric cars through towns, attracting attention while showing that solar energy actually powered the motors in the cars.

But he wanted something more exciting to attract public attention. Then he came up with the idea for a competitive race of solar-powered cars. That inspiration turned out to be right on target, and the Tour de Sol was born.

Muntwyler worked with two other solar experts, Josef Jenni and Markus Heimlicher. Together they prepared a comprehensive set of regulations for the Tour de Sol, an international road rally for solar electric vehicles. In November 1984, they issued the first official announcement for the race.

On June 23, 1985, there were 58 cars registered at the Tour de Sol starting line near Winterthur, Switzerland. The competitors were an eclectic mix of individuals and companies, including an engineering school, an inventive farmer, and Mercedes-Benz. Much to their surprise, the drivers encountered a receptive public all along the race route. Traveling on secondary roads in Switzerland, these vehicles were a moving public display of solar technology. Thousands of onlookers crowded the roads to witness the world's first solar car race. Their enthusiastic cheers carried a clear message to Muntwyler—the timing was perfect.

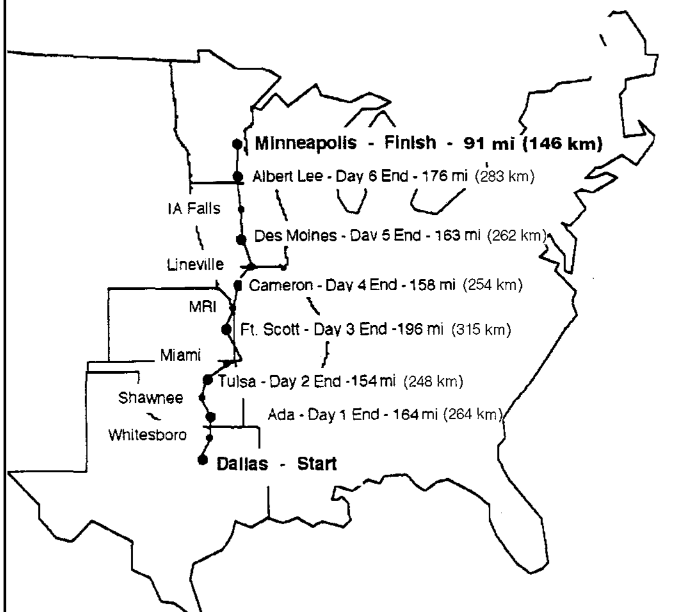
With that incredible beginning, Muntwyler was hooked on the concept of solar racing. All but four of the 58 entrants in the first Tour de Sol completed the 368 kilometer (229 mile) race. Many others expressed an interest in the competition. Everyone encouraged Muntwyler to organize another event to keep the concept alive. As a result, the Tour de Sol became an annual event in Europe, attracting more entrants each year.

Determined to make a difference in the world's energy consumption, MacCready wanted to push technology to its outer limits. Impatient with leaders in the transportation industry, Tholstrup wanted to force technology forward. Eager to reach out to the people with solar technology, Muntwyler wanted to stimulate public awareness. Unwilling to accept any idea as "impossible," these three pioneers blazed a trail that would inspire thousands of other scientists and engineers to challenge the status quo. In striving for a brighter energy future, a cleaner environment, and new applications of advanced technologies, today's efforts to design and build solar cars have surpassed everyone's expectations.

And so the new sport of sunracing began. Sunrayce 93 was the second major cross-country race held in North America (Sunrayce 90 was the first). MacCready, Tholstrup, and Muntwyler were on hand to share in the excitement of this successful event that was inspired by their pioneering work.

by RICHARD KING
Sunrayce Director; U.S. Department of Energy
September 1993

Chapter 1



The Beginning

Sunrayce 93 was announced on August 19, 1991, and invitations were sent to all colleges, universities, trade schools, and other higher educational institutions in North America. Out of 64 proposals, 36 teams were selected to participate. The participating teams had a year and a half to design and build their cars.

The race began on June 20, 1993, in Arlington, Texas and finished in Minneapolis, Minnesota, on June 26, covering over 1740 kilometers (1100 miles) in seven days. The quickest car to complete the course won the race. The challenge for the teams was to power their race cars only with sunlight.

Racing began at 9:00 a.m. each morning and ended at 6:30 p.m., giving teams 9-1/2 hours to reach the daily finish line. The race route followed secondary state and county roads in normal traffic. Each day there was a mandatory 15-minute midday stop.

Sunrayce 93 competitors represented a wide range of educational disciplines and geographical regions. Teams came from two- and four-year colleges and universities throughout North America. Canada, Puerto Rico, the District of Columbia, and twenty-one other states including Hawaii were also represented in the race.

Table 1
The Schedule

Day	**Date**	**Location**	**Activity**
Sunday	June 20, 1993	Arlington Stadium; Arlington, Texas	Race start from lot
Sunday	June 20, 1993	Main Street; Whitesboro, Texas	Midday stop
Sunday	June 20, 1993	Ada High School; Ada, Oklahoma	Overnight stop
Monday	June 21, 1993	K-Mart; Shawnee, Oklahoma	Midday stop
Monday	June 21, 1993	Tulsa Fairgrounds; Tulsa, Oklahoma	Overnight stop
Tuesday	June 22, 1993	Wal-Mart; Miami, Oklahoma	Midday stop
Tuesday	June 22, 1993	Fort Scott Comm. Coll.; Fort Scott, Kansas	Overnight stop
Wednesday	June 23, 1993	Midwest Res. Institute; Kansas City, Missouri	Midday stop
Wednesday	June 23, 1993	Cameron High School; Cameron, Missouri	Overnight stop
Thursday	June 24, 1993	Lineville Town Square; Lineville, Iowa	Midday stop
Thursday	June 24, 1993	Iowa State Fairgrounds, Des Moines, Iowa	Overnight stop
Friday	June 25, 1993	Wal-Mart; Iowa Falls, Iowa	Midday stop
Friday	June 25, 1993	Albert Lea Fairgrounds; Albert Lea, Minnesota	Overnight stop
Saturday	June 26, 1993	Minneapolis Zoo; Minneapolis, Minnesota	Race Finish

Table 1 contains a list of the teams and car names and numbers.

There were four rule changes from the 1990 GM Sunrayce USA that had a significant effect on Sunrayce 93. (For the complete rules, please see **Sunrayce 93 Regulations** [1]). First, each team was required to participate in one of two regional qualifiers held two months before the race. This new requirement forced teams to have their car in a roadworthy condition well before the race began, which gave them more testing time. Overall, this rule change helped improve the quality of the solar race cars.

Second, teams were allowed to recharge their cars from the sun at any time during the race day. Unlike the 1990 race, during which recharging was only allowed from 6:30 p.m. to 8:30 p.m. and 7:00 a.m. to 9:00 a.m., teams could recharge as soon as they arrived at the daily finish line. This rule change helped to increase the overall speed of the race.

Third, solar cells were limited to terrestrial-grade cells at a price not to exceed $10 per watt. The intent of this rule restriction was to ensure that teams would not spend excessive amounts of money for aerospace-grade cells to gain a competitive advantage. High-quality aerospace cells are not only very expensive, but they are also in short supply and are not available to everyone, whether or not they have the money. This rule change allows innovation and technological excellence, but prevents any single team from gaining an unfair advantage. In Sunrayce 93, it helped level the playing field and gave the teams with less money a better chance of doing well.

Similarly, the fourth rule change restricted the choice of batteries to commercially available lead-acid type only. The intent was to help reduce the overall cost of the car and to give the students experience working with the kind of batteries they were likely to see in electric vehicles in the near future.

The technical challenge of eking the greatest amount of energy out of eight square meters (86.4 square feet) of sunlight to power a car has brought a blossoming of creative engineering ideas. The U.S. Department of Energy, General Motors Corporation, and all the sponsors are getting a good educational return on their investment as they pass the torch to a new generation of young scientists and engineers.

1. King, R. et al. ***Sunrayce 93 Regulations***. *January 1993. U.S. DOE special publication.*

Table 2

SUNRAYCE 93 Team Car Names and Numbers

Team	Car Name	Car #
Arizona State University	Solar Phoenix	45
Auburn University	Sol of Auburn	11
California State Polytechnic, Pomona	Intrepid	25
California State University, Fresno	Sun Shark	14
California State University, Los Angeles	Solar Eagle II	19
Clarkson University	Excelsior	4
Colorado State University	Solar Ram	32
Drexel University	Sun Dragon	76
Iowa State University	PrISUm II	9
Kauai Community College	Ka'a La O Kaua'i	8
Mankato State University	Northern Light II	3
McGill University	Ra Power	66
Mercer University	Sun Scream	90
New Mexico Tech	Zia Roadrunner	49
Purdue University	The Boilermaker Solar Special	37
Queens University	Sun Quest	100
Reed College	Soltrain	137
Rochester Institute of Technology	Spirit	10
Rose-Hulman Instituite of Technology	Solar Phantom II	74
Stanford University	Sun Burner	101
Stark Technical College	Solar Clipper	222
The George Washington University	Sunforce 1	7
University of California, Berkeley	California Dreamin'	254
University of Maryland	Pride of Maryland II	2
University of Massachusetts, Lowell	Sunblazer	413
University of Michigan	Maize & Blue	1
University of Minnesota	Aurora	35
University of Missouri, Columbia	Sun Tiger	43
University of Missouri, Rolla	Sol Survivor	42
University of Oklahoma	Spirit of Oklahoma II	31
University of Ottawa	Team Ralos II	125
University of Puerto Rico	Discovery	500
University of Texas, Austin	Texas Native Sun	36
University of Waterloo	Midnight Sun	24
Virginia Tech	Solaray II	6
Western Michigan University	Sun Seeker	93

Table 3

SUNRAYCE 93 First Day Places

	Start*	24 Km (15 Mi)	124.9 Km (77.6 Mi)	176.7 Km (109.8 Mi)	Finish 261.6 Km (162.6 Mi)
1	CSU Los Angeles	CSU Los Angeles	Michigan	Michigan	Michigan
2	Drexel	Maryland	CSU Fresno	Cal Poly Pomona	Cal Poly Pomona
3	Virginia Tech	CSU Fresno	Cal Poly Pomona	George Wash.	George Wash.
4	Mankato	Michigan	Kauai	Kauai	Stanford
5	Cal Poly Pomona	U Missouri Columbia	George Wash.	Stanford	Kauai
6	Auburn	Stanford	Maryland	Maryland	U Mass Lowell
7	Stark	Kauai	Arizona State	U Mass Lowell	Maryland
8	U Missouri Columbia	George Wash.	Sranford	Arizona State	Arizona State
9	CSU Fresno	Mankato	Mankato	Mankato	Iowa State
10	Michigan	Cal Poly Pomona	U Mass Lowell	W Michigan	W Michigan
11	Colorado State	Oklahoma	W Michigan	U Missouri Columbia	McGill
12	Minnesota	Minnesota	Oklahoma	Virginia Tech	Virginia Tech
13	Rose-Hulman	U Mass Lowell	Iowa State	Stark	Oklahoma
14	New Mexico	Mercer	U Missouri Columbia	—	Mankato
15	George Wash.	Auburn	Virginia Tech	—	Queens
16	Puerto Rico	Drexel	Stark	—	U Missouri Columbia
17	Mercer	Puerto Rico	McGill	—	CSU Los Angeles
18	RIT	Colorado State	Minnesota	—	Minnesota
19	Iowa State	Arizona State	Puerto Rico	—	Colorado State
20	U Missouri Rolla	Rose-Hulman	Drexel	—	Stark
21	Oklahoma	Queens	RIT	—	UC Berkeley
22	U Mass Lowell	W Michigan	Rose-Hulman	—	RIT
23	Arizona State	McGill	Queens	—	CSU Fresno
24	UC Berkeley	Virginia Tech	Auburn	—	Drexel
25	McGill	Iowa State	CSU Los Angeles	—	Rose-Hulman
26	W Michigan	New Mexico	Mercer	—	Ottawa
27	U Texas Austin	Ottawa	New Mexico	—	Clarkson
28	Waterloo	Stark	Waterloo	—	Puerto Rico
29	Queens	Clarkson	U Missouri Rolla	—	U Texas Austin
30	Kauai	U Missouri Rolla	—	—	Auburn
31	Ottawa	RIT	—	—	Waterloo
32	Stanford	Waterloo	—	—	U Missouri Rolla
33	Clarkson	UC Berkeley	—	—	Mercer
34	Maryland	U Texas Austin	—	—	New Mexico

* The first day starting order was determined by the qualifying place.

Chapter 2

The Cars and Qualifying

Because there had already been a handful of solar car races worldwide, there were plenty of successful designs for the competitors to examine and improve upon in Sunrayce 93. The Sunrayce 93 cars were strongly evolutionary rather than revolutionary. Although the designs are quite varied, a single type of car has not yet proven itself clearly superior. Tables 1 and 2, Chapter 3 provide detailed race results.

The Arlington Convention Center, where 34 teams are working on their solar cars in preparation for scrutineering and the race start.

Solar Car Shapes

Of the starters, the overall body shapes could be grouped into four general categories—Unified Aero Body and Panel Cars, Separate Cab and Panel Cars, Catamaran Type Cars, and Unique Vehicles.

Unified Aero Body and Panel

The first category includes vehicles which integrate the body and solar array into a single aerodynamically shaped package (see Figure 1). The majority of the Sunrayce 93 entrants fell into this category (25 vehicles).

Historically, the first car of this type was the General Motors Sunraycer which won the 3004 km (1867 mile) World Solar Challenge (WSC) in Australia in 1987 (1). The Sunraycer held the WSC speed record (66.889 kph or 41.572 mph) until the November 1993 WSC, when the record was broken by the Honda Dream travelling 84.94 kph (52.79 mph). The Sunraycer also held the world record for sustained speed under solar power alone (78.378 kph or 48.712 mph) until the 1993 WSC. Seven of the entries in the Sunrayce 93 were direct adaptations of the original GM Sunraycer shape, but none finished higher than 18th in Sunrayce 93. In vehicles of this type, the solar array is located behind the driver's compartment (see Figure 1a).

In 1990, Biel Engineering University in Switzerland won the WSC with a clever modification of the Sunraycer shape. Their design included a flat-top panel, three wheels and a clear streamlined cockpit canopy that gave the driver a wide range of vision. The solar cells were placed behind the driver. This shape had a smaller frontal area, a lower weight, and was easier to construct than the Sunraycer. In addition, the speed potential of the Biel car was greater than that of the GM Sunraycer, given equal power input.

Unfortunately, the Biel silicon solar array could not produce as much power as the gallium-arsenide array of the Sunraycer. Consequently, Biel narrowly missed beating the GM record in 1990 (65.16 kph [40.50 mph] versus 66.89 kph [41.57 mph]). Twelve of the Sunrayce 93 cars were adaptations of the Biel shape. The best included 4th place George Washington University and 6th place Maryland (see Figure 1b).

Another successful solar entry in the 1990 WSC was Hoxan's Phoebus III, which had a top section similar to the Sunraycer. This car, however, used three wheels and carefully streamlined front wheel fairings that swiveled. The solar cells were placed behind the driver. In Sunrayce 93, one car, Cal Poly Pomona's Intrepid, used a hybrid of the Biel/Sunraycer shape plus the streamlined wheel skirts of the Phoebus to produce a beautiful and very fast car (Figure 1c). Pomona's Intrepid led overall for two days and ultimately finished second in Sunrayce 93.

Five other teams also modified the Biel shape to produce very distinctive and innovative cars. They accomplished this by placing a clear cockpit canopy towards the center of the solar array and mounting solar cells over the top surface both in front of and behind the driver. This design allows a shorter and lighter car (Figure 1d). The lengths of the cars were all five meters (16.4 feet) or less, about one meter (3.3 feet) shorter than the other designs. Three of the cars used side solar panels (CSU Los Angeles, Oklahoma, and Mankato), which help to make up for the lost solar cell space occupied by the canopy. All five cars that used this design finished in the top half of the field, led by CSU Los Angeles in 3rd place and the University of Oklahoma in 8th. James Worden of the Massachusetts Institute of Technology, together with the University of Waterloo, pioneered this promising body architecture in the 1990 GM Sunrayce USA. The addition of side solar panels enhanced the performance of cars using this design in 1993.

Separate Cab and Panel

The second category of solar vehicles dates from the beginning of solar racing a decade ago. These cars use a fixed or tilting flat solar panel, and a separate driver cab with outrigger front wheels (Figure 2). They are simple, lightweight, relatively inexpensive to build, and reasonably fast. Five cars fell into this category. Because of the greater aerodynamic drag inherent in this design and its unavoidable vulnerability to gusty winds, these multi-surface solar cars are not generally competitive at present. The best of the class in the Sunrayce 93, Rose-Hulman, did finish 15th, however.

Sunrayce 93 organizer Richard King talks to team members at the Eastern qualifier at the Indianapolis Motor Speedway, April 8, 1993.

The University of Oklahoma's car runs though the slalom course at Phoenix. In the car handling test, vehicles had to maneuver through the course in less than 45 seconds to qualify.

The GM winners circle for the fastest qualifiers at the Arlington Convention Center. GM awarded $1000 each to the fastest qualifiers which were (from L to R), Virginia Tech [79.64 kph [49.50 mph]), CSU Los Angeles (80.51 kph [50.04 mph]), and Drexel University [79.76 kph [49.57 mph]).

The Regulations

In order to provide insight into race procedures and the constraints on car systems design, we will briefly summarize the official Sunrayce 93 regulations. For the complete regulations, please see **Sunrayce 93 Regulations** (2). In essence, the rules were quite simple. A car could be no more than 6 meters (19.7 feet) long, 2 meters (6.6 feet) wide and 1.6 meters (5.3 feet) high, with a minimum height of 1 meter (3.3 feet). During the race, the only source of external power permitted without penalty is solar radiation. All of the entries used solar cells, an electric motor, and batteries to store the sun's energy.

The batteries provided auxiliary power for hill climbing and cloudy periods. A full battery charge was permitted at the start, but this was only enough energy to power the car for a few hours. The initial energy stored in the battery represented only about 10% of the total energy used during the race. The rest of the cars' power had to come from solar energy. In the interest of keeping costs down, only lead-acid batteries could be used, with a total capacity of 5 kWh at a 20 hour discharge rate.

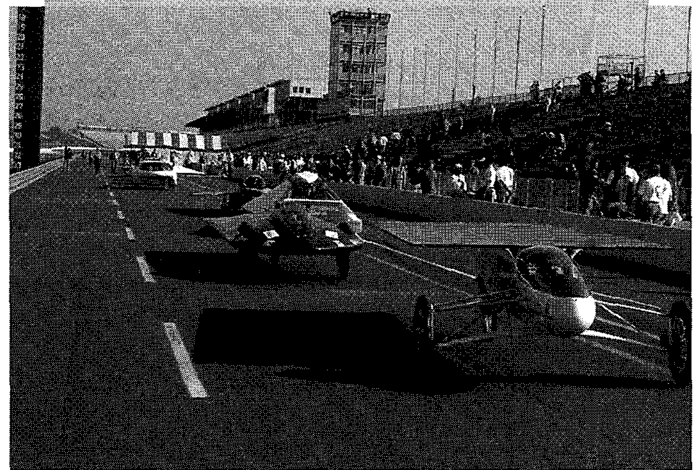
Solar cells had to be terrestrial grade, and could cost no more than $10 per watt. The solar array had to fit in an imaginary right rectangular box no more than 4.4 meters (14.4 feet) long, 2 meters (6.6 feet) wide, and 1.6 meters (5.3 feet) high. Further, the product of length times width could not exceed 8 m^2 (86.4 ft^2). When the car was racing, the maximum array length and width had to be parallel to the ground. In order to maximize solar exposure when the array was charging, however, it could be detached from the car and could assume any orientation in the imaginary box. The entire panel had to be fully visible from the outside when racing. Some teams used these clauses to add an auxiliary panel underneath that was detached and used as an extension to the main panel when the car was stationary and charging. Thus the stationary array could be enlarged to about 2.56 meters (8.4 feet) wide instead of 2 meters (6.6 feet), resulting in a projected panel area of about 10.2 m^2 (110 ft^2) instead of 8 m^2 (86.4 ft^2). There were no regulations regarding motors, gear ratios, or tires.

The many safety provisions included regulations on safety belts; 10 second unassisted driver exit; braking; crush space; roll over protection; safe seating position; structural safety; forward, side and rear vision; electrical wiring; circuit breakers; manual battery and motor disconnects; main fuse; battery and cabin air ventilation; brake and running lights; turn indicators; warning horn; windshield wipers; turning radius, etc. The resulting cars proved to be roadworthy and safe. The safety and design provisions were verified by inspection during a scrutineering period held before the event and at the qualifiers.

Qualifying

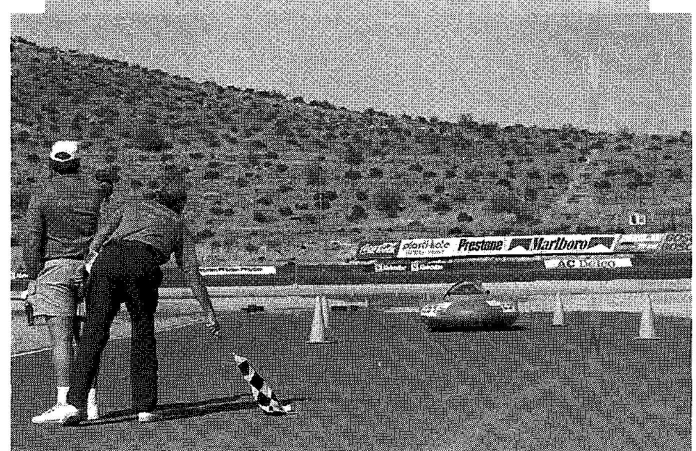
In order to ensure that the cars were roadworthy and passed scrutineering inspection before the Sunrayce started, three qualifying sessions were held: the Eastern Qualifier at Indianapolis Motor Speedway, April 9-10, 1993; the Western Qualifier at Phoenix International Raceway, April 16-17, 1993; and the Last Chance qualifier at Arlington, Texas, June 15-16, 1993. These events generated an atmosphere of excitement and racing fever that proved irresistible and contagious to the competitors. At historic Indy, each team had their own garage and pit area, which added to the feeling that this was an authentic race and not just a classroom exercise.

The Eastern and Western qualifiers were scheduled early enough to give incentive to the teams to have their cars completed, road tested, and qualified before beginning of the race in Arlington. But, before they were even allowed to qualify, cars had to pass scrutineering at four stations to ensure compliance with the structural and safety requirements. The stations were the sizing, body, electrical, and mechanical stations. In addition, the cars had to pass three moving tests: handling, in which they had to weave through a 200 meter (656 foot) slalom course in 45 seconds; braking, which involved stopping in a straight line at 0.43 g's deceleration; and finally the actual qualifying or speed test in which they had to travel 80.5 km (50 miles), averaging 32.2 kph (20 mph) or more. The 80.5 km (50 mile) distance was chosen to establish the durability of the cars.



The Rose-Hulman car standing in the lineup at the Indianapolis Eastern qualifier on April 10, 1993. The cars had to run 20 laps—80 kilometers (50 miles)—averaging 32 kph (20 mph) or more. Visible behind Rose-Hulman are Virginia Tech, Stark, Clarkson, and Iowa State.

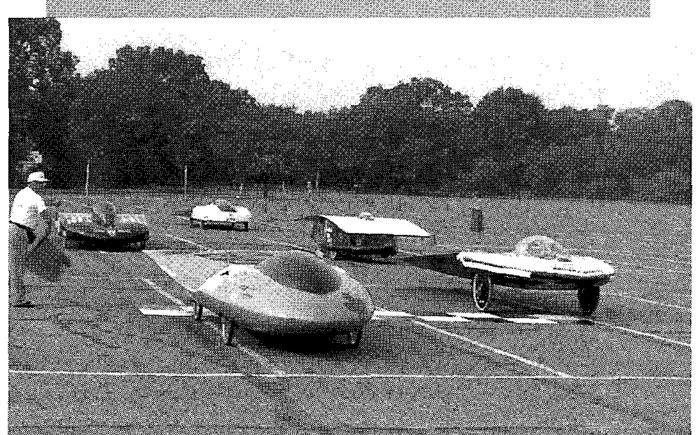
It wasn't necessary for the cars to be in finished form before the Eastern or Western qualifiers, but they had to be mobile enough to pass the braking, handling, and speed tests. Waiting until the last minute was the rule at Indy, Phoenix, and even at Arlington. Only 12 of the 36 cars were completed by April and a few were not even finished at the beginning of the race. Fortunately, 34 cars were approved to race, but the process was nerve-racking for some of the entrants as well as many of the officials.



To pass the braking test, cars had to decelerate at 0.43 G's or greater. Official Dan Eberle measures the initial speed with a radar gun and Ward Phillips gives UC Berkeley the stop flag.

Twenty-five cars qualified at Indianapolis and Phoenix. Some barely made it before the track closed at about 4 p.m. The Rose-Hulman Phantom had a series of heart-stopping time delays. First, spokes kept working loose in their wheels, which took repair time in the morning. Then a blown circuit board had to be replaced and hardwired in, which delayed them in the afternoon. When the Phantom was finally back on the track, they had to complete 15 laps in one hour, an average speed of 61 kph (38 mph). With four laps to go, the Phantom blew a fuse and during repairs another fuse blew. To the thrill of the home state crowd, Rose-Hulman qualified at Indianapolis with just seconds to spare.

It also looked as though Mercer University would not qualify. A bearing seized in their continuously variable transmission and they frantically scurried around town trying to find a replacement. They couldn't locate one. But Rose-Hulman performed a last-minute rescue by loaning them a replacement bearing. Unfortunately, Mercer stalled on the last lap just as the track closed. Sympathetic officials decided to count Mercer's practice lap, however, which brought their total up to the required distance.



John Agnello of General Motors starts the Last Chance qualifier, held in the Arlington Convention Center parking lot on June 16, 1993. From front to back are Queens University (Canada), Maryland, Stanford, McGill University (Canada), and Western Michigan University.

Five teams failed the early qualification: Clarkson because of electrical problems; Maryland due to a broken steering linkage; Purdue because of instability and an incomplete car; Texas because of braking problems plus a wheel and suspension failure; and Western Michigan due to a broken suspension. Six teams didn't come to either the Eastern or Western qualifiers and had to wait until Arlington. The remaining five teams were not required to attend a regional qualifier because of the great distance and associated cost of making the trip. In addition, Kauai Community College was hit hard by a hurricane but recovered beautifully. Stanford had a battery fire which destroyed their chassis and panel (which they rebuilt in time for the race). Like Kauai Community College, the Canadian teams of McGill, Queens, Ottawa, and Waterloo later qualified in Arlington.

Table 2
Sunrayce 93 — Awards

OVERALL WINNERS		
1st Place	Michigan	$6,000
2nd Place	Cal Poly Pomona	$5,000
3rd Place	CSU Los Angeles	$4,000
GMAC 1st Place Award	Michigan	$25,000
EAGLE PICHER Award	Michigan	Silver Zinc Batteries
WESTINGHOUSE Winners Circle Award	Michigan	$5,000
DUPONT Award, Best use of Composites		
	Cal Poly Pomona	$5,000
TECHNICAL INNOVATION AWARD - Solar Array		
1st Place	George Washington	$1,000
2nd Place	Maryland	$800
3rd Place	Rose-Hulman	$600
TECHNICAL INNOVATION AWARD - Body, Chassis, Aerodynamics		
1st Place	Stanford	$1,000
2nd Place	CSU Los Angeles	$800
3rd Place	Cal Poly Pomona	$600
TEAMWORK AWARD		
1st Place	U Mass Lowell	$1,000
2nd Place	McGill University	$800
3rd Place	Stark Technical College	$600
GOOD SPORTSMANSHIP AWARD		
1st Place	CSU Fresno	$1,000
2nd Place	Mankato	$800
3rd Place	W Michigan	$600
ALEM Safety Award	George Washington	$250
KICKOFF BANQUET AWARDS		
CHEVROLET RQ Winners Circle Awards (Top Qualifiers)		
1st Place	CSU Los Angeles	$1,000
2nd Place	Drexel	$1,000
3rd Place	Virginia Tech	$1,000
SAE Award for Engineering Excellence		
	U Mass Lowell	$1,000
DOE Award for Artistic Design		
1st Place	Cal Poly Pomona	$500
2nd Place	Kauai	$400
3rd Place	Michigan	$300

DAILY AWARDS — (Finishing order normally before Penalties)

	1st Place	2nd Place	3rd Place	Teamwork	Sportsmanship
DAY 1	Michigan	Cal Poly Pomona	George Wash	Maryland	Oklahoma
DAY 2	Cal Poly Pomona	Michigan	George Wash	Maryland	Oklahoma
DAY 3	Cal Poly Pomona	Michigan	George Wash	W Michigan	Puerto Rico
DAY 4	CSU Los Angeles	George Wash	Michigan	Stark	Mercer
DAY 5	Iowa State	Michigan	Cal Poly Pomona	U Mass Lowell	U Missouri Columbia
DAY 6	CSU Los Angeles	Cal Poly Pomona	George Wash	U Texas Austin	McGill
DAY 7	CSU Los Angeles	George Wash	Maryland	Virginia Tech	Waterloo

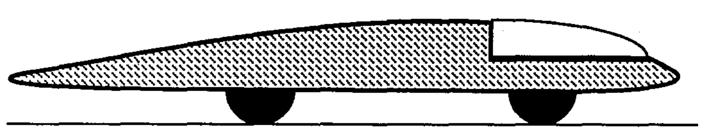
In all, 10 teams qualified in Arlington, but it was close for Clarkson and Waterloo. Clarkson spent much of the day tightening loose spokes, and Waterloo made some last minute repairs to their brakes, steering, and suspension. All told, the scrutineering and qualification process was amazingly successful. Only Purdue was hit by irrevocable bad luck. First they shattered a weak injection molded plastic bicycle drive wheel while running. When they left the car in the parking lot to try to find a replacement, a sudden rain and wind storm wrecked the car, soaking their electronics and damaging the vehicle beyond repair. Purdue was out of the race, but they were still allowed to participate as official assistants. The Reed College team withdrew before the race, but they also followed along as assistants.

There was a hot competition among teams for the Chevrolet Qualifying Winners Circle Awards, which amounted to $1000 to each of the top three qualifiers. After completing the mandatory 80.5 kilometer (50 mile) distance, teams were allowed to run additional laps until the track closed, with only the fastest laps counting toward the average speed. At Indianapolis, Drexel and Virginia Tech took several breathers to charge their batteries and came back to run some very fast times toward the end of the day, which displaced their slower laps. They traded first and second places repeatedly until, on their last lap, Drexel pulled into the lead with an average speed of 79.8 kph (49.57 mph), beating Virginia Tech's 79.6 kph (49.50 mph). Rochester Institute of Technology ran the fastest lap at Indy, averaging 91.6 (56.96 mph).

The 4 kilometer (2.5 mile) oval at Indy was faster than the 1.6 kilometer (1 mile) track at Phoenix. In fact, many of the cars had trouble with flat tires caused by scrubbing on the shorter radius of curvature at Phoenix . It was a real achievement, therefore, for CSU Los Angeles to take the pole at 80.5 kph (50.04 mph). Their fastest lap on the one mile oval was an amazing 92.1 kph (57.24) mph. Los Angeles went back on the track late in the afternoon and raised their average speed from 80.39 kph (49.96 mph) to 80.5 kph (50.04 mph) just to break the 80.5 kph (50 mph) barrier. Racing fever is hard to avoid in such an atmosphere. For complete qualifying speeds and places, see Tables 1 and 2, Chapter 3.

References

1. Kyle, C.R. ***Racing with the Sun***. *The 1990 World Solar Challenge. Society of Automotive Engineers, Warrendale PA. 1991.*
2. King, R. *et al.* ***Sunrayce 93 Regulations***. *January 1993. U.S. DOE special publication.*



Chapter 3

The Race

Race Logistics

During the cross-country race, the solar panel could be exposed to the sun for motive power and battery charging during daylight hours, from 6:30 a.m. until 8:30 p.m., with the cars impounded under official security from 9 p.m. until 6:30 a.m. While impounded, the cars could not be touched by team members. There was a limit of four drivers who could rotate turns operating the vehicle as desired. Each driver was ballasted up to a minimum of 80 kg (176 lbs).

Each racing day started at 9 a.m. with vehicles leaving at 1 minute intervals in the order of their previous day's finish. The final race finishing order was determined by the sum of the daily elapsed times. Vehicles that failed to complete the daily distance were given the time difference between their scheduled start and 6:30 p.m. plus a penalty of four minutes per mile not covered (example: 43 miles not covered and a 9:31 a.m. start = 539 min. + 4 x 43 min = 711 min = 11 hours, 51 minutes).

There were additional time penalties for traffic violations or other infractions. The heaviest penalty was for battery replacement. Basically it was (in minutes) three times the length of the day's leg when it occurred, with credit given for partial replacement. Five teams were forced to absorb battery penalties when they replaced damaged cells. The penalties ranged from only 19 minutes for Clarkson University who replaced just two cells, to 9 hours and 43 minutes for Drexel University who replaced their whole battery pack.

Battling the Competition and the Weather

If adversity is the real test of performance, then the Sunrayce 93 was the most successful solar car competition in history. An encyclopedia of obstacles confronted the competitors. The race started under cloudy skies in Arlington and this was just a preview. Along the way, 64 kph (40 mph) winds, torrential rains, lightning storms, and grades too steep to climb (with lifeless batteries) challenged the teams.

By day five people were jokingly referring to Sunrayce 93 as the great American Cloud Race, the Midwestern Trailer Rally, or the Kansas Submarine Regatta. There were only two days of clear sunshine out of seven (the last two days). Sometimes teams had to seek refuge from storms and wind wherever they could find it—under freeway overpasses, in the shadow of high embankments, or, as a last resort, in the shelter of their own trailers. One team used a friendly neighborhood garage to ride out the worst part of a thunderstorm. Another abandoned the race, trailered their car into clear sunshine in the next state and charged their batteries. They then trailered back into cloudy skies to finish the race.

The start of Sunrayce 93, in front of the Arlington Convention Center. The teams are lined up in order of their qualifying speed. Visible from front to back are CSU Los Angeles, Drexel, Virginia Tech, Mankato State, Cal Poly Pomona, Auburn, Stark Tech.

Conditions weren't ideal, but they could have been worse. After the race, Sunrayce 93 organizers were asking themselves how they possibly could have chosen a period with such bad weather. But a week later, the route became an inland sea under the worst summer floods in history.

The weather certainly served to divide the field in a hurry. The only car to make it to the finish every day under its own power was the University of Michigan. The Maize & Blue, which won the race by 90 minutes, averaged 44 kph (27.3 mph). The second place Intrepid from Cal Poly Pomona averaged 42.3 kph (26.3 mph).

Sunrayce 93 was extremely close until day five when clouds, rain, lightning, and wind halted all of the leaders except Michigan short of the finish. Day five was the turning point. Michigan gained an unbeatable margin that it never relinquished. In third place, three hours and 18 minutes back, was the Solar Eagle II from CSU Los Angeles, which averaged 39.3 kph (24.4 mph). After blowing a motor controller on day one and losing nearly three hours in repairs, Los Angeles climbed from 17th place on the first day to third place overall. The Sunforce I from George Washington University finished fourth with an average of 38.8 kph (24.1 mph), 40 minutes behind CSU Los Angeles (see Tables 1 and 2 for detailed results). Figures 1 and 2, page 21, show the daily progress of the top twelve cars (1).

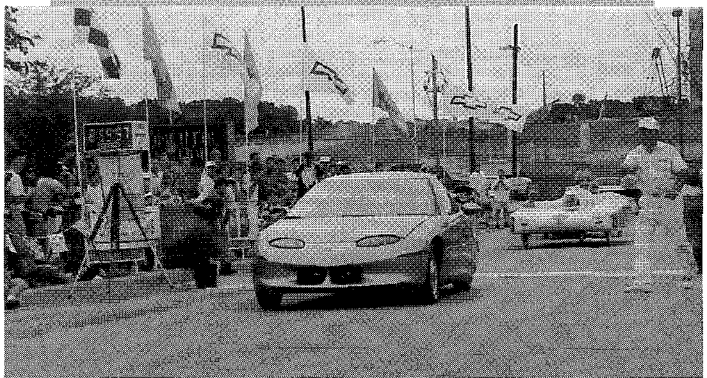
At the end of day four, there was a tight pack of three cars leading the field—Pomona, Michigan, and George Washington. Pomona was ahead by 10 minutes. Second place Michigan would have been leading, except for two traffic penalties totaling 30 minutes levied on day three and day four. Following closely was George Washington, only 42 minutes behind Michigan. At this point, any one of the three might have won if the weather had cooperated.

But it didn't. Day five started with a lightning and rain

Table 1

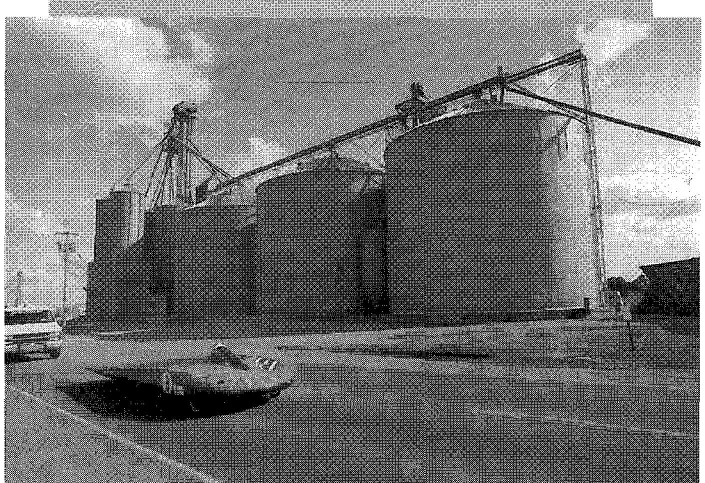
SUNRAYCE 93 Official Results

	Team	Qualifying Place	Qualifying Speed kph(mph)	Finishing Time (hours)	Average Speed kph(mph)	Distance km(mi)	Best Daily Place
1	Michigan	10	63.99 (39.77)	40.66	43.91 (27.29)	1785.2 (1109.5)	1 (twice)
2	Cal Poly Pomona	5	73.71 (45.81)	42.16	42.35 (26.32)	1743.4 (1083.5)	1 (twice)
3	CSU Los Angeles	1	80.51 (50.04)	45.45	39.28 (24.41)	1739.0 (1080.8)	1 (3 times)
4	George Washington	15	41.34 (25.69)	46.12	38.71 (24.06)	1660.7 (1032.1)	2 (twice)
5	Stanford	32	36.85 (22.99)	52.81	33.81 (21.01)	1711.7 (1063.8)	4
6	Maryland	34	36.04 (22.40)	55.71	32.05 (19.92)	1634.1 (1015.6)	3
7	Oklahoma	21	40.34 (25.07)	64.31	27.76 (17.25)	1572.3 (977.2)	5
8	U Mass Lowell	22	39.52 (24.56)	66.66	26.79 (16.65)	1376.5 (885.5)	5
9	Kauai	30	39.87 (24.78)	68.88	25.92 (16.11)	1497.8 (930.9)	5
10	Iowa State	19	46.56 (28.94)	70.30	25.39 (15.78)	1618.5 (1005.9)	8
11	McGill	25	39.36 (24.46)	70.58	25.29 (15.72)	1442.0 (896.2)	7
12	CSU Fresno	9	65.81 (40.90)	75.51	23.64 (14.69)	1361.5 (846.2)	4
13	Arizona State	23	70.55 (43.85)	78.07	22.86 (14.21)	1289.8 (801.6)	8
14	Queens	29	37.34 (23.21)	78.25	22.82 (14.18)	1331.0 (827.2)	11
15	Rose-Hulman	13	53.23 (33.08)	79.69	22.40 (13.92)	1258.6 (782.2)	12
16	Mankato	4	77.96 (48.45)	79.88	22.35 (13.89)	1261.8 (784.2)	13
17	Drexel	2	79.76 (49.57)	81.07	22.03 (13.69)	1395.0 (867.0)	6
18	W Michigan	26	36.54 (22.71)	81.16	22.00 (13.67)	1226.4 (762.2)	10
19	U Missouri Columbia	8	69.44 (43.16)	82.95	21.51 (13.37)	1228.1 (763.3)	8
20	Virginia Tech	3	79.65 (49.50)	85.24	20.95 (13.02)	1088.0 (676.2)	9
21	Minnesota	12	56.85 (35.33)	85.29	20.93 (13.01)	1168.8 (726.4)	13
22	RIT	18	55.61 (34.56)	85.76	20.82 (12.94)	1170.1 (727.2)	19
23	Stark	7	69.81 (43.39)	86.03	20.76 (12.90)	1145.1 (711.7)	7
24	Colorado State	11	60.26 (38.45)	87.03	20.51 (12.75)	1114.6 (692.7)	12
25	Auburn	6	71.26 (44.29)	90.07	19.82 (12.32)	1135.0 (705.4)	13
26	Ottawa	31	38.57 (23.97)	90.32	19.76 (12.28)	1100.6 (684.0)	15
27	Puerto Rico	16	36.94 (22.96)	91.10	19.60 (12.18)	1052.3 (654.0)	22
28	Clarkson	33	39.97 (24.84)	91.85	19.44 (12.08)	1056.8 (656.8)	18
29	U Missouri Rolla	20	43.57 (27.08)	96.12	18.57 (11.54)	929.5 (577.7)	21
30	Mercer	17	32.18 (20.00)	96.29	18.54 (11.52)	921.6 (572.8)	12
31	Berkeley	24	35.38 (21.99)	98.43	18.13 (11.27)	876.6 (544.8)	14
32	Texas Austin	27	34.95 (21.72)	101.99	17.51 (10.88)	803.7 (499.5)	10
33	Waterloo	28	35.01 (21.76)	108.16	16.51 (10.26)	667.9 (415.1)	27
34	New Mexico	14	51.34 (31.91)	117.80	15.32 (9.42)	542.6 (337.2)	22



The revolutionary electric GM Impact was the official Sunrayce 93 pace car. The battery- and electric motor-powered Impact has a range of about 193 kilometers (120 miles), is lightweight, uses low rolling resistance/high pressure tires, and has the lowest aerodynamic drag coefficient of any production automobile.

Third place winner, CSU Los Angeles, starts day five in Cameron, Missouri under stormy skies so dark that headlights were necessary. Los Angeles has a wing shaped unified aerodynamic body with a separate cockpit canopy and side solar panels. This body type was pioneered by James Worden of MIT and by the University of Waterloo in the 1990 Sunrayce.



Kauai Community College drives past huge grain elevators in Iowa. Except for a few large cities, the scenery on the Sunrayce 93 route was mostly colorful, rural farm country.

from 15th to 34th. This phenomenon highlighted the distinction between battery power and solar power. High qualifying speeds are mostly due to stored battery energy, while fast race speeds are primarily the result of an efficient solar array, minimum power losses in the drive train, and a fundamentally effective and reliable vehicle.

Two teams did extremely well under the overcast conditions of the first five days, probably because of their huge side solar arrays. The University of Oklahoma (7th) and Iowa State University (10th) cars featured large side solar panels which could efficiently absorb the diffuse global radiation typical of cloud cover. In addition, Oklahoma had the lightest car in the race at 205 kg (452 lbs.).

Probably the most surprising dark horse, however, was Stanford University. If there was a contest for sheer enclosed volume, the fifth place finisher Stanford "Sunburner" was the runaway champion. Designed as a two-passenger car for the World Solar Challenge in Australia, where the rules permit the entire surface of a two passenger vehicle to be covered with solar cells, the Sunburner was stripped down for Sunrayce 93. In jest, Stanford was accused of building the only solar Pullman car with a sleeping compartment. Despite its size, and because of its simple construction, Stanford's weight of 349 kg (770 lbs) was about average. The shape of the car, however, was extraordinary. A wave form, awning-like solar panel covered the immense aerodynamically shaped body. The car was extremely reliable and unexpectedly fast for its size.

Rounding out the top ten were three beautifully finished cars, Maryland (6th), the University of Massachusetts at Lowell (8th), and Kauai Community College (9th). Their basic shapes had evolved from the Biel car (winner of the 1990 World Solar Challenge). Kauai, with its good-natured crew, its brilliant blue and gold graphics, and its meticulously smooth paint finish, was the spectators' and photographers' favorite along the race route. The team members were favorites in the evening as well, because several times they performed their lilting island music and Hawaiian dancing. Kauai also placed first among the two-year colleges and finished ahead of most of their distinguished four-year brethren—quite an accomplishment for a small isolated technical program.

The bad weather had the effect of quickly sorting out the efficient and weatherproof solar cars from their less energy-efficient companions. All but two of the first eleven cars on day 1 stayed in the top eleven. All of the first eleven on day 2 remained in front for the duration, with only minor shifts in placement (Table 1, page 17). Some spirited mini-races took place within the field. Iowa State (10th) changed places four times with McGill (11th). Iowa finally moved into the lead on day six, beating McGill by only 17 minutes after seven days of racing. Arizona State (13th) and Queens (14th) switched places twice, with Arizona edging out Queens by just 11 minutes.

Some of the teams were slow to gain momentum, but once they did, they moved rapidly through the field. CSU Los Angeles was the comeback champion. After completely replacing their powertrain during the first two days, they advanced 14 places from 17th to 3rd. Without the first day breakdown, Los Angeles would have been a serious competitor for first place. CSU Fresno recovered from a short circuit in their panel which drained their batteries the first two days and then moved from 25th to 12th after day three. Rose-Hulman and Drexel also

Figure 1 - Cumulative average speed versus day, places 1-6

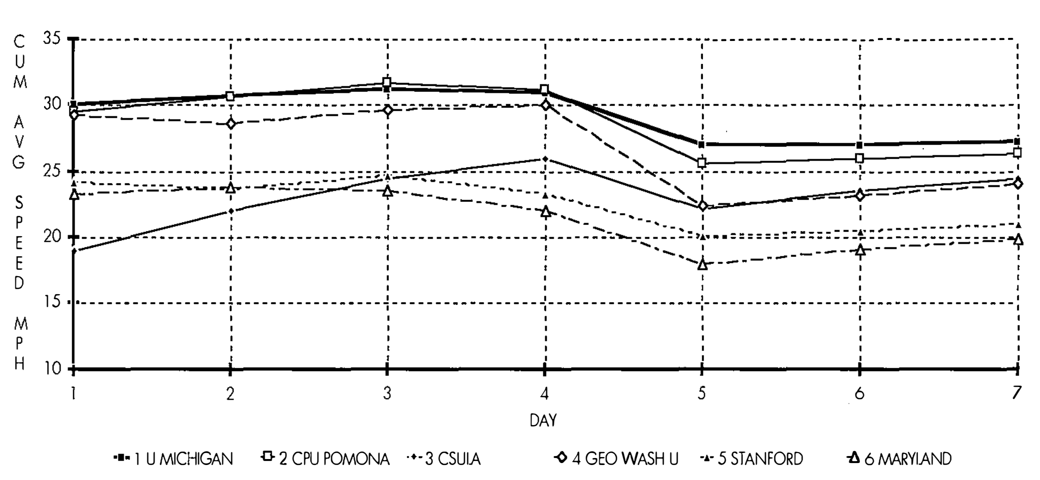


Figure 2 - Cumulative average speed versus day, places 7-12

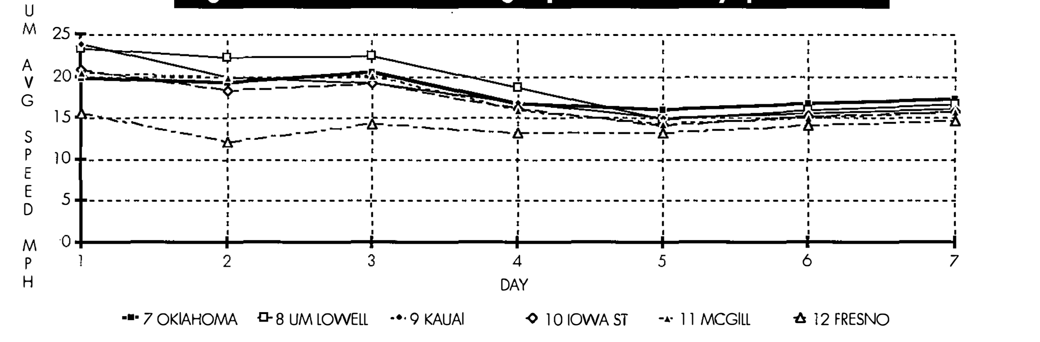


Figure 3 - Speed versus day, places 1-6

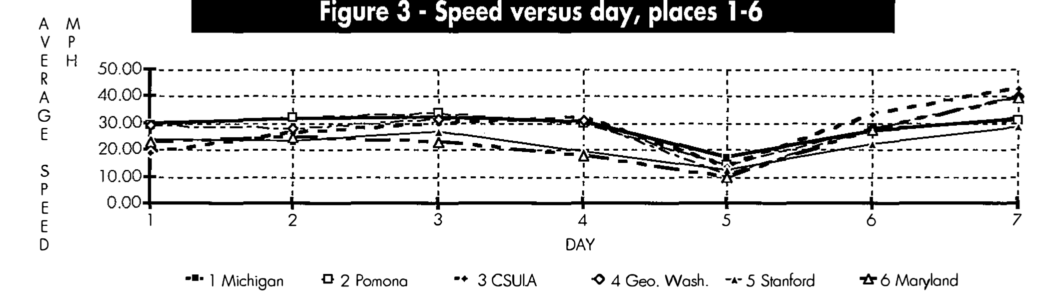
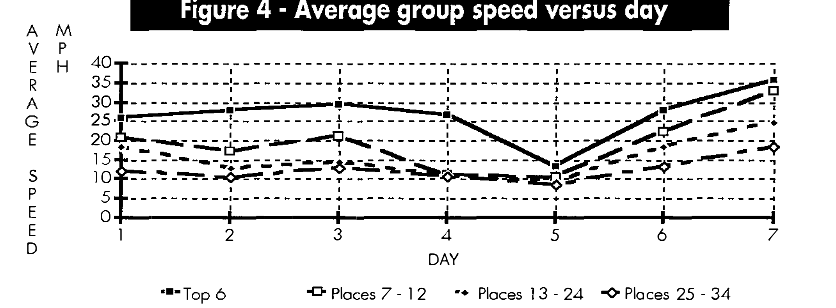


Figure 4 - Average group speed versus day



made inspiring comebacks. Rose-Hulman advanced 10 places from 25th to 15th, and Drexel made it from 24th to 17th during the last three days. If conditions had been ideal, the final results might have been very different, but that's sunracing.

In order to complete each daily stage by 6:30 p.m., the cars had to average from 27 to 32 kph (17 to 20 mph), depending upon the length of the stages. Although all of the cars had qualifying speeds of 32 kph (20 mph) or higher, most of the entrants had problems maintaining this pace during the race. None of the cars in the bottom two-thirds of the field finished more than three days. These disappointing results were reversed on the sixth day, when the sun came out—two-thirds of the cars made it in by 6:30 p.m.

If the final placements had been decided according to miles traveled instead of adjusted time, (see Table 1, page 17), some of the field would have shuffled one or two places, but the essential results would have remained unchanged. Only three teams would have shifted more than two places. Iowa would have moved up from 10th to 7th, Drexel from 17th to 12th, and Virginia Tech would have moved back from 20th to 26th. However, both Iowa and Drexel replaced their batteries when they were hopelessly depleted and therefore were able to gain extra miles. Even with 9 hours of battery penalty, both of them did very well overall.

In fact, Iowa accomplished a major publicity coup when their batteries were fortuitously exchanged on day four. The next day proved to be the worst day of the race and to the delight of the Iowa press and TV, the Iowa car made it into the State Fair Grounds in Des Moines under its own power—the first to finish for the day. They drove out of the Fair Grounds in pole position the next morning (Michigan was the only other car to finish day five under its own power).

On the other hand, Virginia Tech's story was different. When the sun was shining, the Solaray II was a very fast car. Because of the low efficiency of its solar cells (13.9%), however, the car was much slower than average when it was cloudy. Overall, the rules worked remarkably well. The results were decided almost entirely by actual performance, not on the basis of penalties.

The thing that seemed to influence placing more than anything else was reliability and practice time. As former Michigan Team Leader Susan Fancy commented, "Often it isn't the fastest car that wins, but the best team." The leading 10 cars averaged 1287 kilometers (800 miles) of practice before the race. The winning Michigan team covered the entire race course twice and practiced over 4827 kilometers (3000 miles). The last ten places averaged only 257 kilometers (160 miles) of practice before the race and the middle group averaged 402 kilometers (250 miles). In other words, if you are prepared, your chances of finishing at the front of the field are much better. Getting enough practice and learning to solve problems before the race is a matter of planning, organization, and teamwork.

Was the race too hard? Not really. It accomplished exactly what it set out to do, namely to reward energy conservation, efficiency, team work, reliability, and innovative use of technology. There could be no doubt about the winners—they met the goals of the competition with flair.

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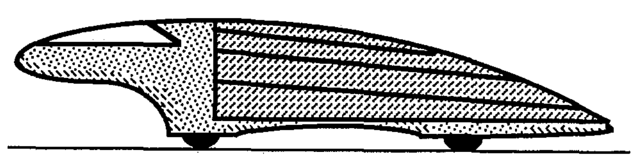
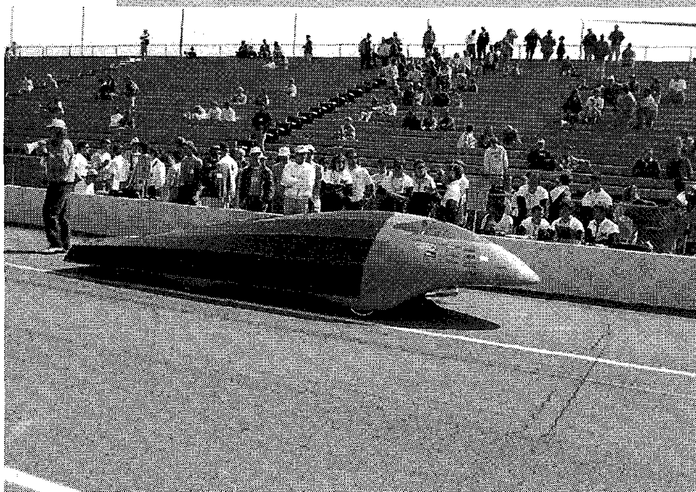
1. *Basore, P.A. "Sunrayce 93: Collegiate Competition Introduces American Public to Photovoltaics". Published in* Progress in Photovoltaics: Research and Applications, *v1, 311-318, 1993. John Wiley and Sons, Ltd.*

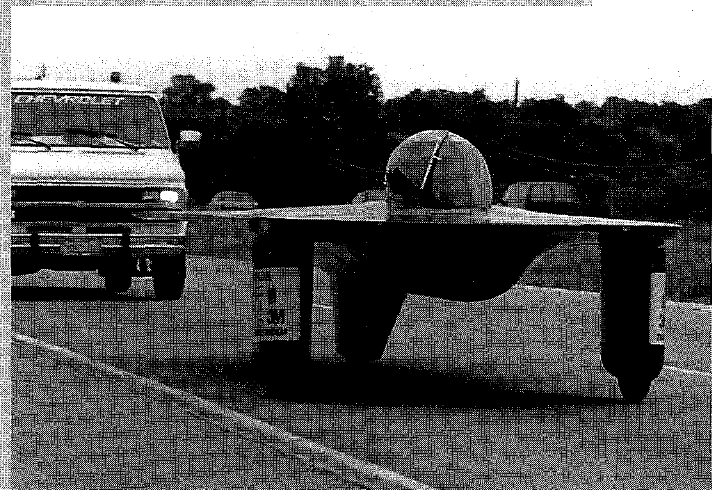


The Entrants



1st Place

***#1* University of Michigan "Maize and Blue."** *USA*
Time: 40.66 hrs Distance: 1785.2 km (1109.5 mi)
Average Speed: 43.92 kph (27.29 mph)



2nd Place

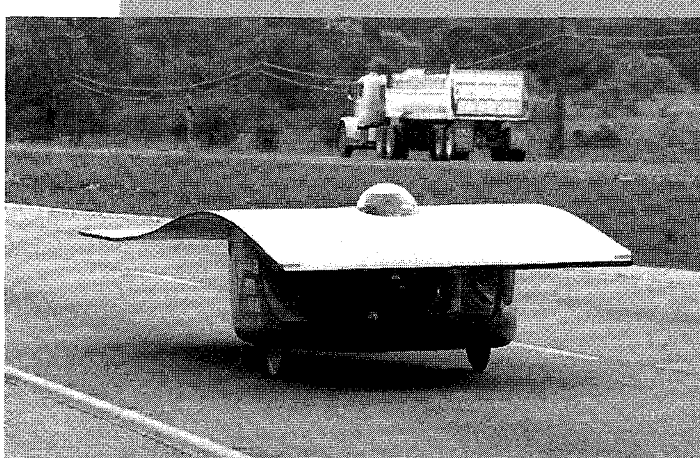
***#25* California State Polytechnic, Pomona "Intrepid."** *USA*
Time: 42.16 hrs Distance: 1743.4 km (1083.5 mi)
Average Speed: 42.36 kph (26.32 mph)

3rd Place

***#19* California State University, Los Angeles "Solar Eagle II."** *USA.*
Time: 45.45 hrs Distance: 1739 km (1080.8 mi)
Average Speed: 39.28 kph (24.41 mph)

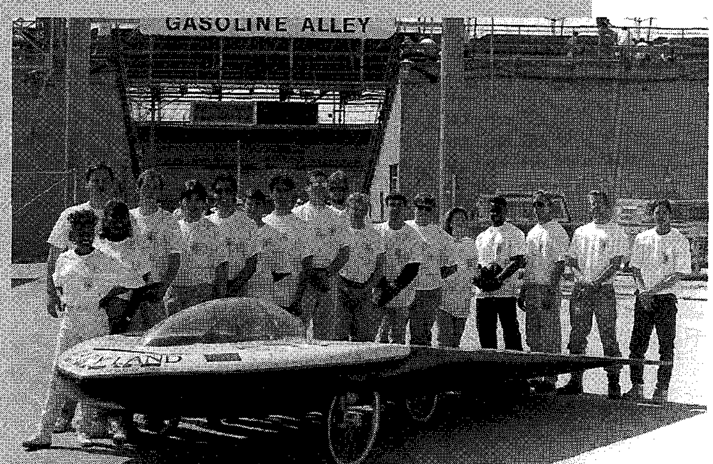
4th Place

***#7T* The George Washington University "Sunforce I."** *USA*
Time: 46.12 hrs Distance: 1660.6 km (1032.1 mi)
Average Speed: 38.72 kph (24.06 mph)



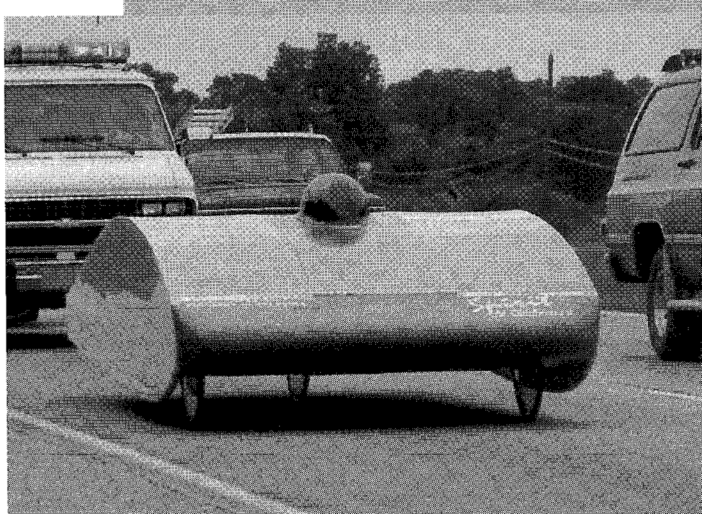
5th Place

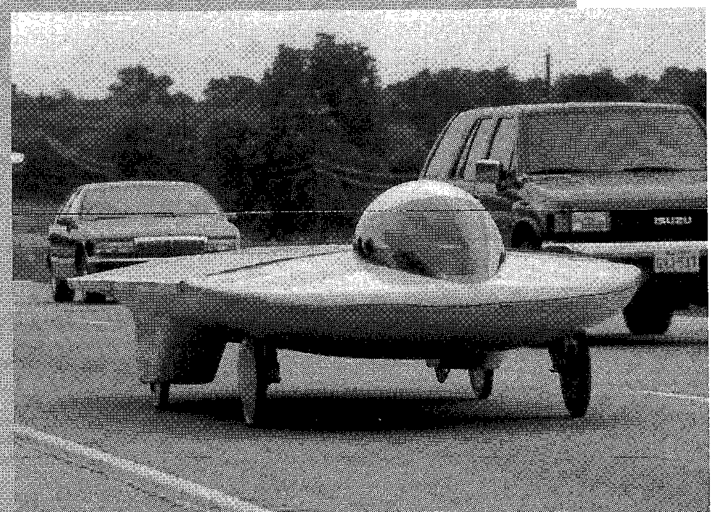
***#101* Stanford University "Sunburner."** *USA*
Time: 52.81 hrs Distance: 1711.7 km (1063.8 mi)
Average Speed: 33.81 kph (21.01 mph)



6th Place

***#2* University of Maryland "Pride of Maryland II."** *USA*
Time: 55.71 hrs Distance: 1634.1 km (1015.6 mi)
Average Speed: 32.06 kph (19.92 mph)



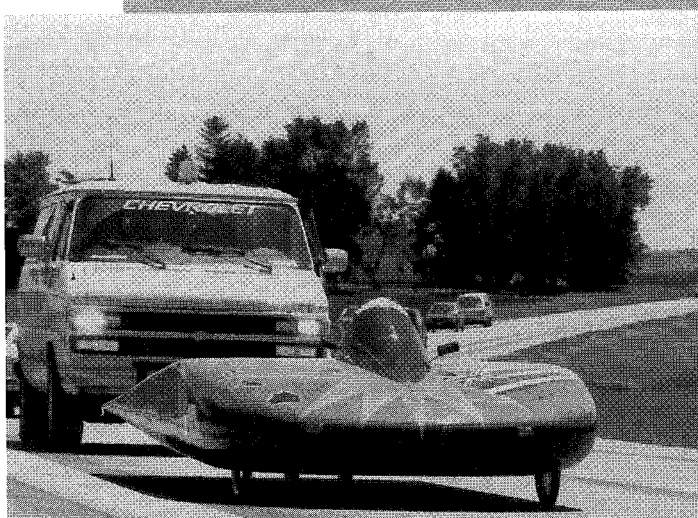


7th Place

#31 University of Oklahoma "Spirit of Oklahoma II." USA
Time: 64.31 hrs Distance: 1572.3 km (977.2 mi)
Average Speed: 27.76 kph (17.25 mph)

8th Place

#413 University of Massachusetts, Lowell. "Sunblazer." USA
Time: 66.66 hrs Distance: 1424.8 km (885.5 mi)
Average Speed: 26.79 kph (16.65 mph)

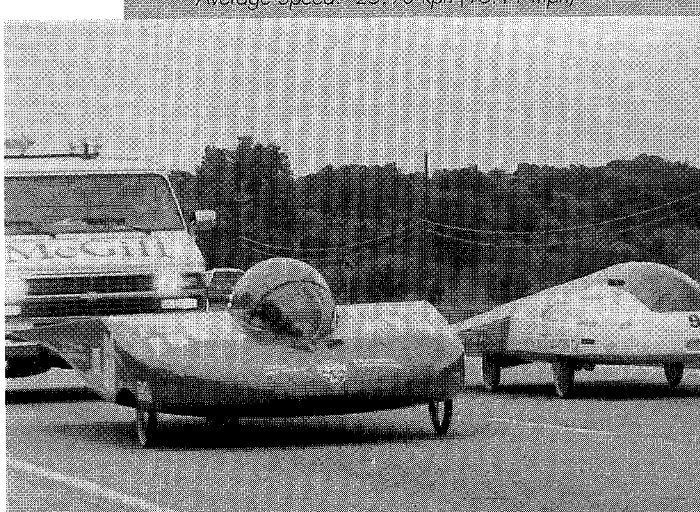


9th Place

#8 Kauai Community College "Ka'a La O Kaua'i." USA
Time: 66.88 hrs Distance: 1497.8 km (930.9 mi)
Average Speed: 25.93 kph (16.11 mph)

10th Place

#9 Iowa State University "PrISUm II." USA
Time: 70.30 hrs Distance: 1618.5 km (1005.9 mi)
Average Speed: 25.39 kph (15.78 mph)

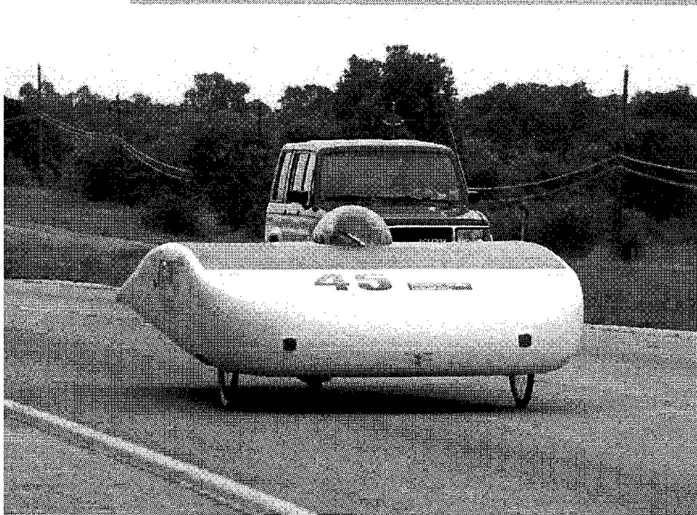


11th Place

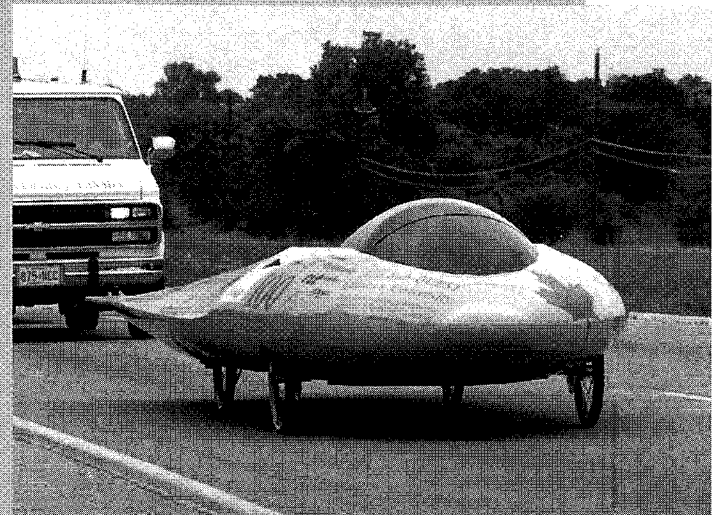
#66 McGill University "Ra Power." Canada
Time: 70.58 hrs Distance: 1442.0 km (896.2 mi)
Average Speed: 25.30 kph (15.72 mph)

12th Place

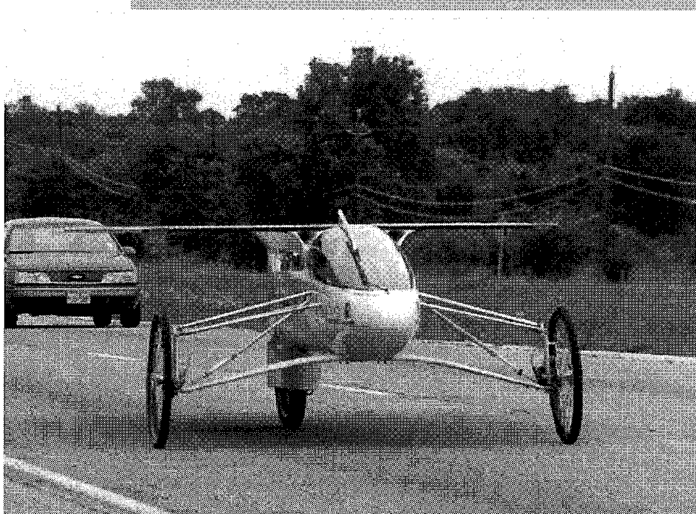
#14 California State University, Fresno "Sun Shark." USA
Time: 75.51 hrs Distance: 1361.5 km (846.2 mi)
Average Speed: 23.64 kph (14.69 mph)



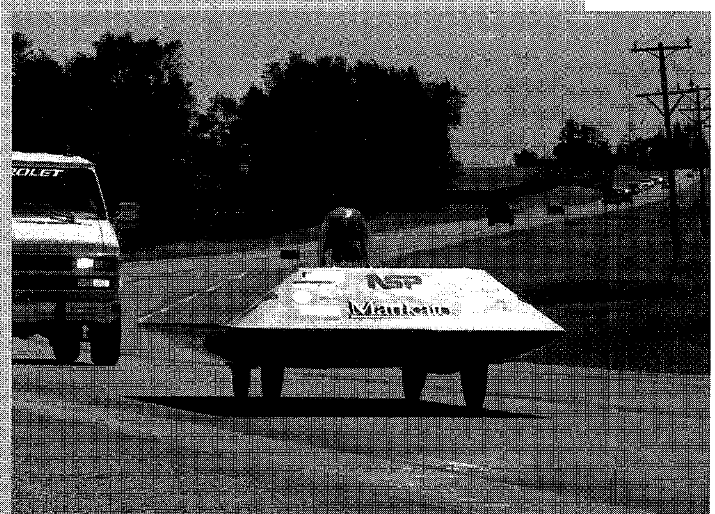
13th Place **#45 Arizona State University "Solar Phoenix."** USA
Time: 78.07 hrs Distance: 1289.8 km (801.6 mi)
Average Speed: 22.87 kph (14.21 mph)



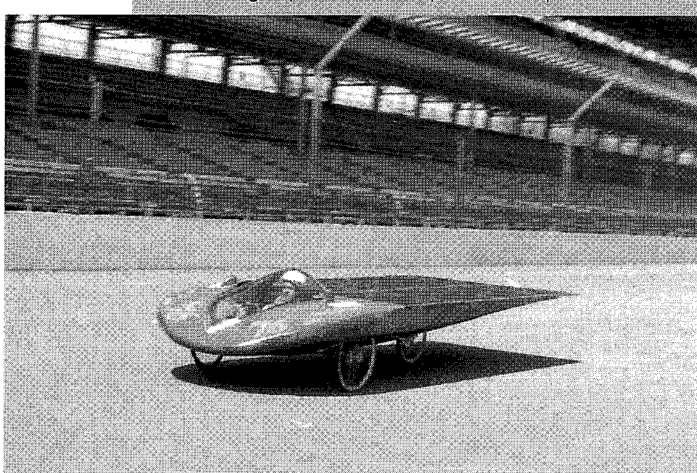
#100 Queens University "Sun Quest." Canada 14th Place
Time: 78.25 hrs Distance: 1331.0 km (827.2 mi)
Average Speed: 22.82 kph (14.18 mph)



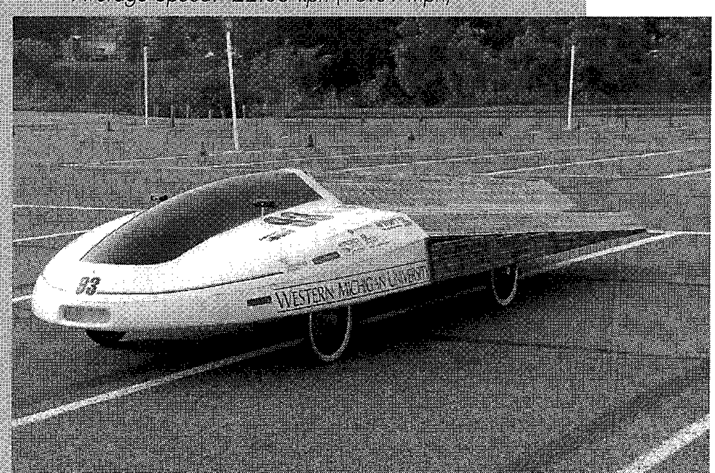
15th Place **#74 Rose-Hulman Institute of Technology "Solar Phantom II."** USA.
Time: 79.69 hrs Distance: 12158.6 km (782.2 mi)
Average Speed: 22.40 kph (13.92 mph)



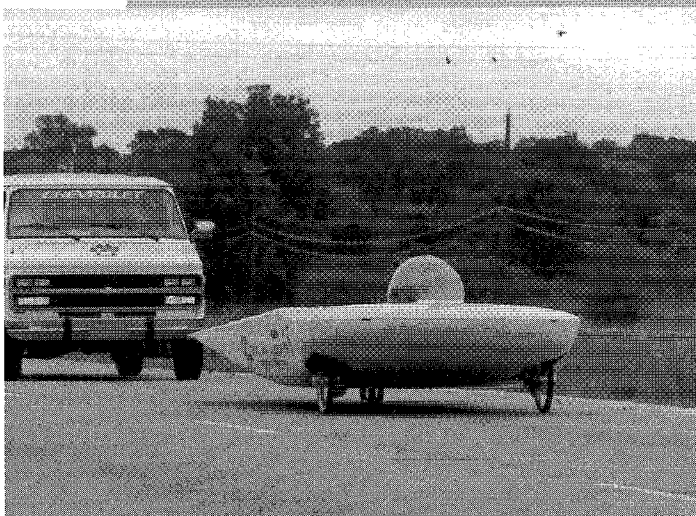
#3 Mankato State University "Northern Light II." USA 16th Place
Time: 79.88 hrs Distance: 1261.8 km (784.2 mi)
Average Speed: 22.35 kph (13.89 mph)



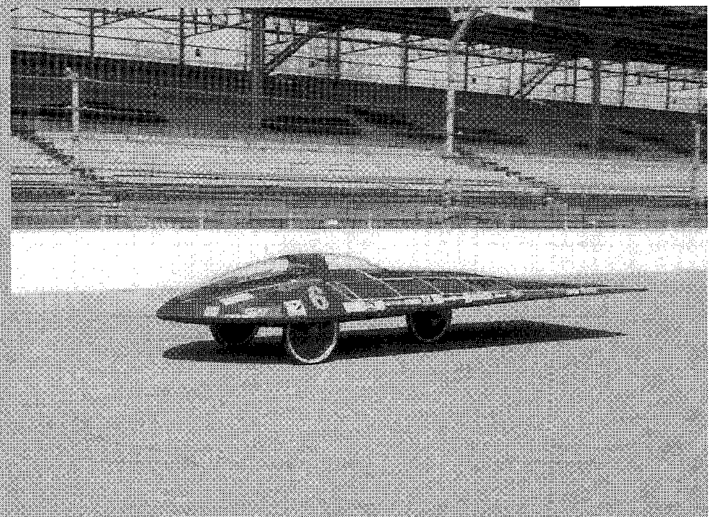
17th Place **#76 Drexel University "Sun Dragon."** USA
Time: 81.07 hrs Distance: 1395.0 km (867.0 mi)
Average Speed: 22.03 kph (13.69 mph)



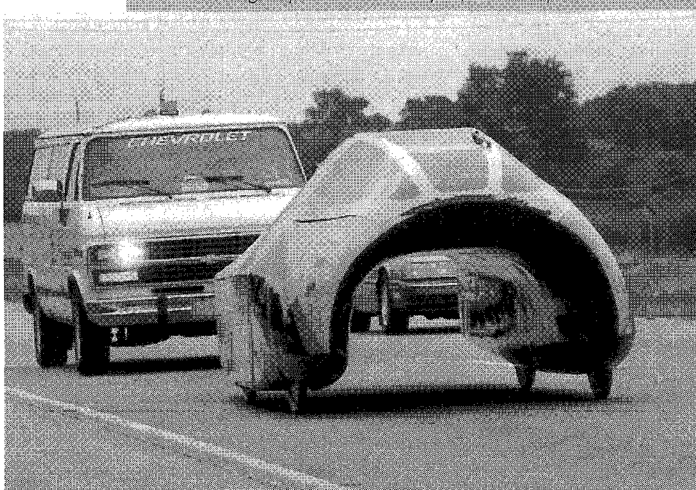
#93 Western Michigan Univ. "Sun Seeker." USA 18th Place
Time: 81.16 hrs Distance: 1226.4 km (762.2 mi)
Average Speed: 22.00 kph (13.67 mph)



19th Place **#43 University of Missouri, Columbia "Sun Tiger."** USA
Time: 82.95 hrs Distance: 1228.1 km (763.3 mi)
Average Speed: 21.52 kph (13.37 mph)



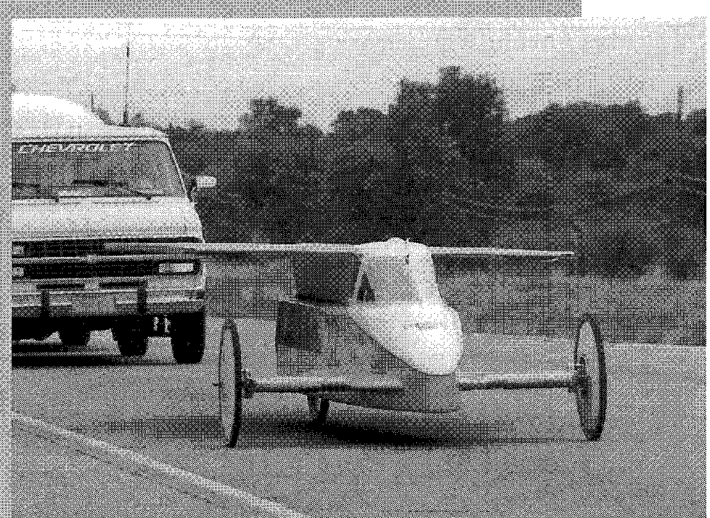
#6 Virginia Polytechnic Institute "Solaray II." USA 20th Place
Time: 85.24 hrs Distance: 1088.0 km (676.2 mi)
Average Speed: 20.95 kph (13.02 mph)



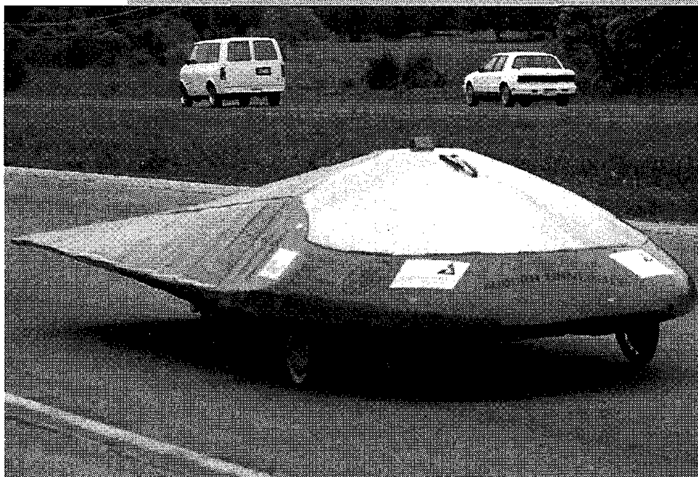
21st Place **#35 University of Minnesota "Aurora."** USA
Time: 85.29 hrs Distance: 1168.8 km (726.4 mi)
Average Speed: 20.94 kph (13.01 mph)

#10 Rochester Institute of Technology "Spirit." USA 22nd Place
Time: 85.76 hrs Distance: 1170.1 km (727.2 mi)
Average Speed: 20.82 kph (12.94 mph)

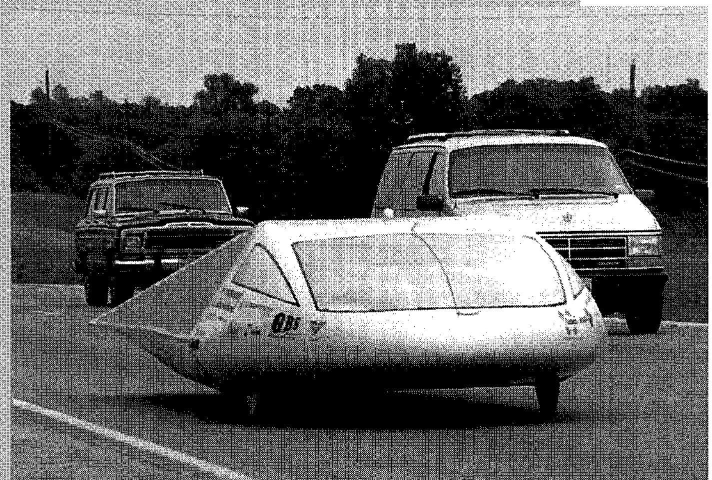
23rd Place **#222 Stark Technical College "Solar Clipper."** USA
Time: 86.03 hrs Distance: 1145.1 km (711.7 mi)
Average Speed: 20.76 kph (12.90 mph)



#32 Colorado State University "Solar Ram." USA 24th Place
Time: 87.03 hrs Distance: 1114.6 km (692.7 mi)
Average Speed: 20.52 kph (12.75 mph)

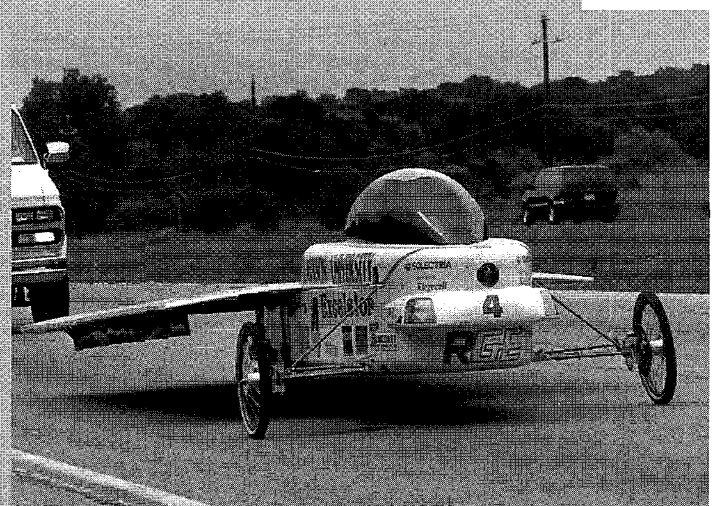


25th Place **#11 Auburn University "Sol of Auburn."** USA
Time: 90.07 hrs Distance: 1135.0 km (705.4 mi)
Average Speed: 19.83 kph (12.32 mph)

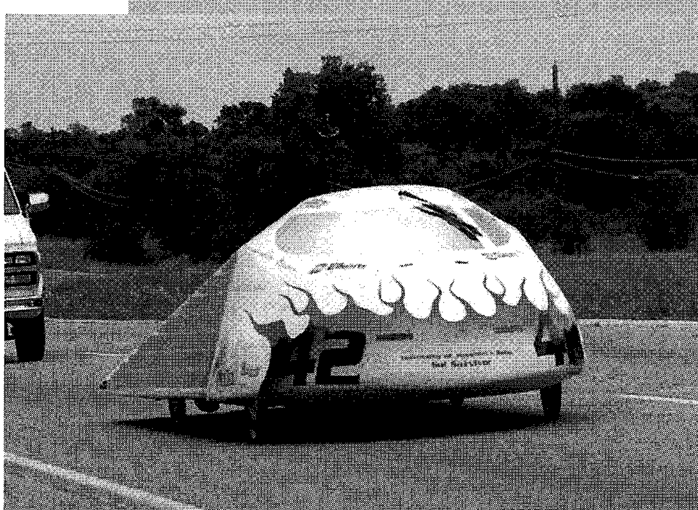


#125 University of Ottawa "Team Ralos II." Canada 26th Place
Time: 90.32 hrs Distance: 1100.6 km (684.0 mi)
Average Speed: 19.76 kph (12.28 mph)

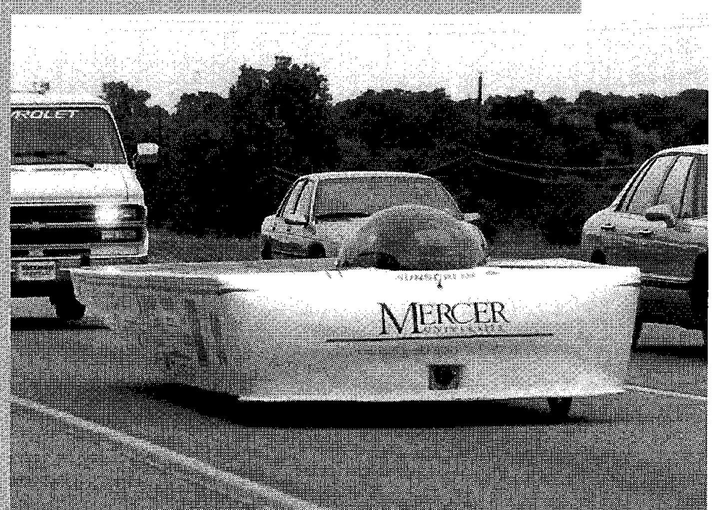
27th Place **#500 University of Puerto Rico "Discovery."** USA
Time: 91.10 hrs Distance: 1052.3 km (654.0 mi)
Average Speed: 19.60 kph (12.18 mph)



#4 Clarkson University "Excelsior." USA 28th Place
Time: 91.85 hrs Distance: 1056.8 km (656.8 mi)
Average Speed: 19.44 kph (12.08 mph)

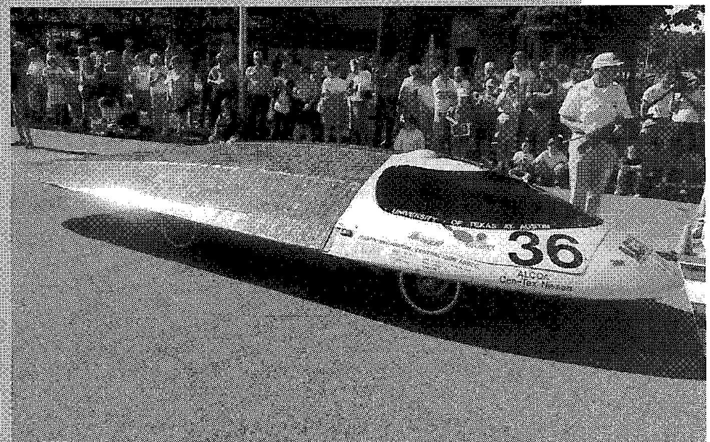


29th Place **#42 University of Missouri, Rolla "Sol Survivor."** USA
Time: 96.12 hrs Distance: 929.5 km (577.7 mi)
Average Speed: 18.57 kph (11.54 mph)

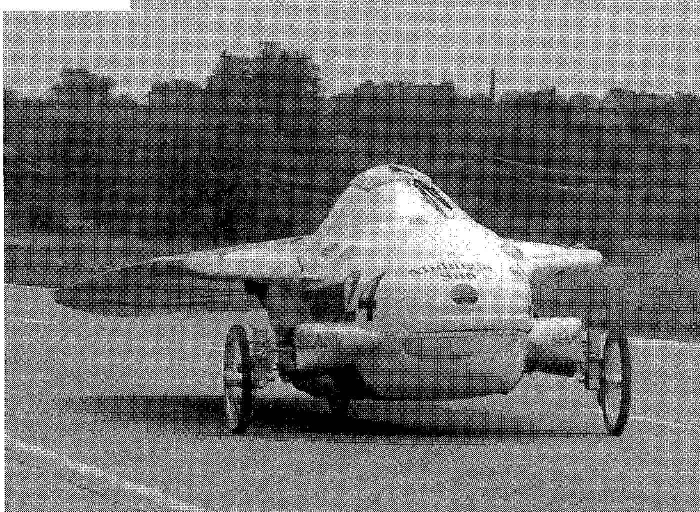


#90 Mercer University "Sun Scream." USA 30th Place
Time: 96.29 hrs Distance: 921.6 km (572.8 mi)
Average Speed: 18.54 kph (11.52 mph)

31st Place **#254 University of California, Berkeley. "California Dreamin."** USA.
Time: 98.43 hrs Distance: 876.6 km (544.8 mi)
Average Speed: 18.14 kph (11.27 mph)

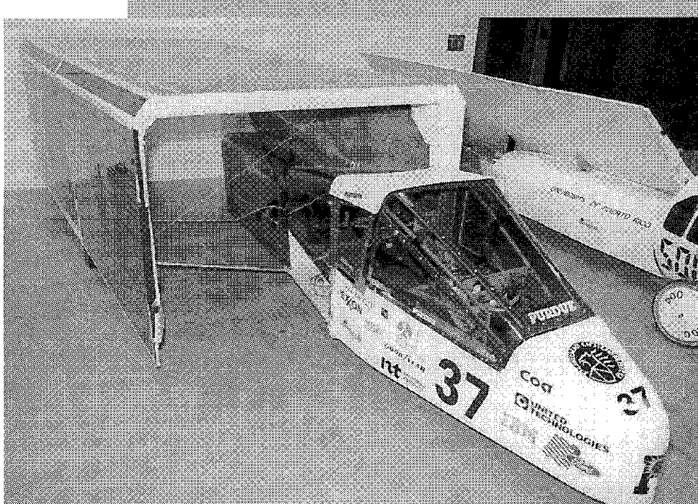


#36 University of Texas, Austin "Texas Native Sun." USA 32nd Place
Time: 101.99 hrs Distance: 803.71 km (499.5 mi)
Average Speed: 17.51 kph (10.88 mph)



33rd Place **#24 University of Waterloo "Midnight Sun."** Canada
Time: 108.16 hrs Distance: 667.9 km (415.1 mi)
Average Speed: 16.46 kph (10.26 mph)

#49 New Mexico Institute of Mining & Technology "Zia Roadrunner." USA. 34th Place
Time: 117.80 hrs Dist: 542.6 km (337.2 mi.)
Avg Speed: 15.11 kph (9.42 mph)



No Finish **#37 Purdue University The Boilermaker Solar Special"** USA.
Withdrew before start in Arlington, due to stability problems.

#137 **Reed College "Soltrain"** USA. No Finish
Withdrew after Phoenix Qualifier, due to lack of resources.

Chapter 4

The People

by JOYCE KYLE

Sunrayce 93 appealed not only to the university and college entrants, but also to throngs of citizens in lawn chairs, pickup trucks, and tractors who lined the race route through the central United States. Sunrayce was fascinating to all these folks, from the youngest race organizational worker, Leo Tsuo, who was 11 and worked with his family at the solar education booth, to the Missouri teachers who volunteered to be observers during their summer vacation. One of its greatest supporters and fans was Robert Stempel, past President of General Motors, who described the Sunrayce as "a safe, fun race, running in all kinds of weather, in which the students can use the solar car as a true-to-life introduction to engineering science."

Why Build a Solar Car?

What attracted so many people with such diverse interests to this two-week event? According to Professor William Dryland of Clarkson University, "Students enroll in engineering, thinking they will do things like this. But they are often disillusioned by the drudgery of pure theory in the classroom. This practical design competition keeps engineering students in school by providing them with an interesting and exciting 'hands on' outlet for their creative ability."

Brent Hart, a member of the Auburn University team, agrees. "This race gave me the opportunity to do what I like most—race and use an alternative energy source, solar energy. I study a lot of theory in school, but I need to have a practical project to stay interested."

Mankato University's Tim Kruse was an auto mechanic for 15 years. He originally majored in business but felt burned out. He now enjoys engineering because, "I believe solar power is the wave of the future. I wanted exposure, experience, and work coordination in the field. This is it!"

Senior students at Queens University in Ontario, Canada, found that working on a solar car provided valuable, practical experience they could put on their resumé. They believe employers want to hire people who know how to get things done, from fund raising to working through a tough problem. A University of Massachusetts team member added that "the real sacrifice of building a solar car while working to support yourself and going to school" shows the true value of an applicant.

Enthusiastic Iowa fans urge the solar cars on with their homemade sign.

Silvia Villeseñor, the only woman on the CU Los Angeles team, is an outgoing, vital person with good mechanical ability. She is currently a civil engineering student and the President of the student chapter of American Society of Civil Engineers. Ms. Villeseñor started as a business major and transferred to civil engineering because she wanted to take a subject that would keep her motivated. She finds it exciting to be learning about technology for the future and feels that the Sunrayce experience has provided tangible proof of her abilities. Silvia postponed her graduation for one year because of the solar car project. "I don't have any regrets," she says. "Sunrayce was a once-in-a-lifetime opportunity."

The UC Berkeley's Dave Azevedo read about the project in the newspaper. He had worked for many years as a mechanic and race car driver and owned his own restaurant when he learned about the Sunrayce. He sold the restaurant and went back to engineering school because he wanted to be a part of the solar car project. Dave says that "the Sunrayce changed my life. Now I'm going to be an engineer, something that will provide far more satisfaction than what I did before."

Building a solar car also taught students on all of the teams practical skills such as welding, composite layup, machine shop operations, etc. When an axle broke on the University of Michigan's Maize & Blue during testing, Andy Carmody had to fix the problem. He went to the shop, took out manuals, and spent 12 hours teaching himself how to use a lathe, then spent three hours making the axle. It worked.

Mankato State passes a mother and children, perched on their family tractor, near Albert Lea, Minnesota.

Richard King becomes an honorary officer in the Union Army at Fort Scott, Kansas.

All along the route, spectators of all ages lined the roads watching the solar cars glide by. This family, near Cameron, Missouri, includes granddad, mother, and children.

Community Support

Building a solar car develops fund raising and business management skills as well as engineering expertise. The participating Sunrayce teams were forced to seek support from industry, the university or college, interested citizens, family, and friends.

Students learned that garnering community support and raising money are important parts of the endeavor. The University of Oklahoma team was uniquely successful at both. The "Spirit of Oklahoma" is painted in the colors of the Oklahoma flag (blue, orange, and white). It was built entirely from donations of one dollar or more from the citizens of Oklahoma. At a special session of the State Legislature, the team formally presented the car to the people of Oklahoma, and in turn the car received Oklahoma license plates. According to Oklahoma faculty advisor John Fagan, "Whether there is little support or a lot, all of the Sunrayce team members are heroes. They have accomplished an amazing amount in a short time with limited budgets and cramped facilities."

Stark Technical College of Ohio had a very large team of supporters who came from most of the departments on campus. Diana Groom, a business student, said that the Stark solar car project is a big morale builder for the tiny two year college. The average age of students at Stark is 28, which they believe gives them an advantage in merchandising their solar car. As a fund raising campaign, they "sold" all of the 950 solar cells on the car to boosters and gave them a map showing the location of their cell.

Often, a network of alumni helped the teams succeed. For example, the University of Michigan's small 43 cm (17 inch) Michelin custom tires showed excessive wear and there was very little time to correct the problem before the race. By chance, an alumni fan had booked a trip to France to visit a French friend who worked for Michelin. When the alumni's friend learned of the difficulty, the friend visited the technicians at Michelin and Michelin provided improved tires to Michigan before the race. The tires worked flawlessly.

The most dedicated Michigan alumnus is sixty-year-old Chuck Hutchins. He is so enthused about the solar car team that he has made four flights to Michigan from California to check on the car's progress, and he followed the Sunrayce all the way. Hutchins explains that "others spend money to fly to the Rose Bowl games, but I would rather spend money to fly to solar car events." Team member Andy Carmody says that on Father's Day Chuck threw his arms around several team members and said, "I'd like to adopt all of you guys." Carmody hugged him and said, "Dad! I need tuition for grad school."

Although many of the teams were heavily supported by faculty and experts from the community, some student groups had to compete almost entirely on their own. According to Alec Tilson, the team captain of Stanford, their project was completely student organized and run. Tilson noted that "It's a struggle to handle all of the details necessary to compete, maybe solving the same problem three or four times until it finally works. But later, the students are really elated because ***they*** solved the problems."

Getting Ready

A last minute, high pressure rush was typical for many of the Sunrayce competitors. The University of Massachusetts advisor, Alan Rux, said that their team was known as the "chain saw bunch" because they came to Arlington with just the molded pieces of their fairings. At Arlington they ground, shaped, and painted the fairings. They were one of the teams that worked all night on the dock behind the exhibition hall to get ready for impounding. UC Berkeley was still gluing on solar cells at the last minute.

Some entries had real problems even getting to the race. CSU Fresno redesigned the whole body of their car while studying for final exams. They worked night and day to extend the solar panel and to do the rebuilding. Dr. John Seevers, the advisor to Fresno's Sun Shark reports that "when things didn't work, they swore they could never make it. Then they would fix it and they would say they were coming. We called Sunrayce Headquarters to see how late we could arrive in Arlington. We drove straight through in 36 hours." The Sun Shark bunch got to Arlington two hours before their time for scrutineering.

The Sunrayce turned out to be a great lesson in improvisation. George Washington University lost their rear view mirror just before the start. Frantically, Jay Newlin took the mirror out of the rental van and broke it into pieces. He epoxied it back onto the hook in the canopy. It didn't work. Meanwhile, other team members found a mirror in the tool kit and soldered it onto the canopy. Other members went out and bought six bike mirrors. The driver liked the tool kit mirror best and used it all through the race.

Another sign of improvisation was the origin of the parts used in car construction. Vehicles from different areas adapted parts from unexpected sources. McGill University from Quebec, Canada, used many snowmobile parts, while vehicles from other locations used shock absorbers, brakes, and drive sprockets from go-carts, motorcycles or weight lifting equipment. Cal Poly Pomona used motorcycle forks with suspensions. Some teams used bicycle brakes or other bike parts. They used almost anything but automobile parts ("they are just too heavy"). In general, the teams used the things they were most familiar with.

The Observers

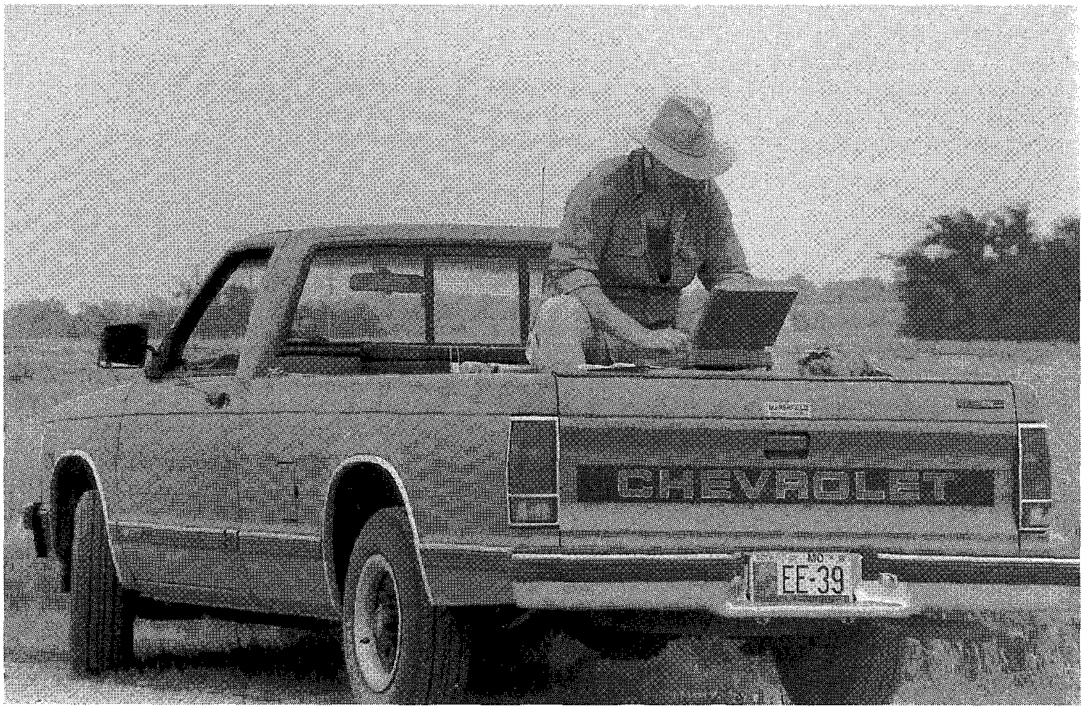
Official observers had to travel with each solar car to make sure team members followed the regulations. The experience of serving as an observer could vary from that of going on a family vacation to living in an experimental lab. On the first night, in Ada, Oklahoma, about 25 observers were sleeping on a carpet in the middle of the Ada High School library. People had to pass through the room to get to the showers. A reading teacher/observer, Cary Tuckey, said "I felt like I was bedded down on I-44!" Observers stayed with one team for half a day and then changed at the noon stop to another car. Despite their hectic schedule, they did a fantastic job.

The observers were mostly Missouri school teachers. Dan Eberle, who was in charge of selecting observers, was looking for volunteers with good teamwork skills, good planning skills and the ability to handle people. He thought Missouri science teachers had all of the needed attributes. Dan selected teachers that had attended an Alternative Energy workshop at Crowder College and who had been teaching science many years.

Team members protect solar cars from a thunderstorm at the start on day five in Cameron, Missouri.

Heavy rains on day five forced cars to seek shelter wherever they could find it.

When Oklahoma pulled to the side of the road to charge their batteries, tall grass shielded the solar panel from the sun. Good-natured team members are flattening the grass so that the sun's rays can reach the solar cells.



A Missouri reporter uses his laptop computer to type out a Sunrayce story from the back of his pickup truck.

Missouri reporter, waiting by the side of the road for the local team to go by (Missouri-Rolla), sat in the bed of his pickup with a beautiful farm in the background, punching in his story on a laptop computer. Pickup trucks with families from granddad to baby sister were watching the solar cars pass. When cars broke down, children came to see the repairs. The kids ran to get water or tools or to help in any way they could. The neighbors came out to talk with the teams.

A young spectator about 12 years old was heard to say as the colorful tiger-striped Rochester Institute of Technology car sped by, "That car looks like it's wearing tiger pants. Is it sponsored by Frosted Flakes?"

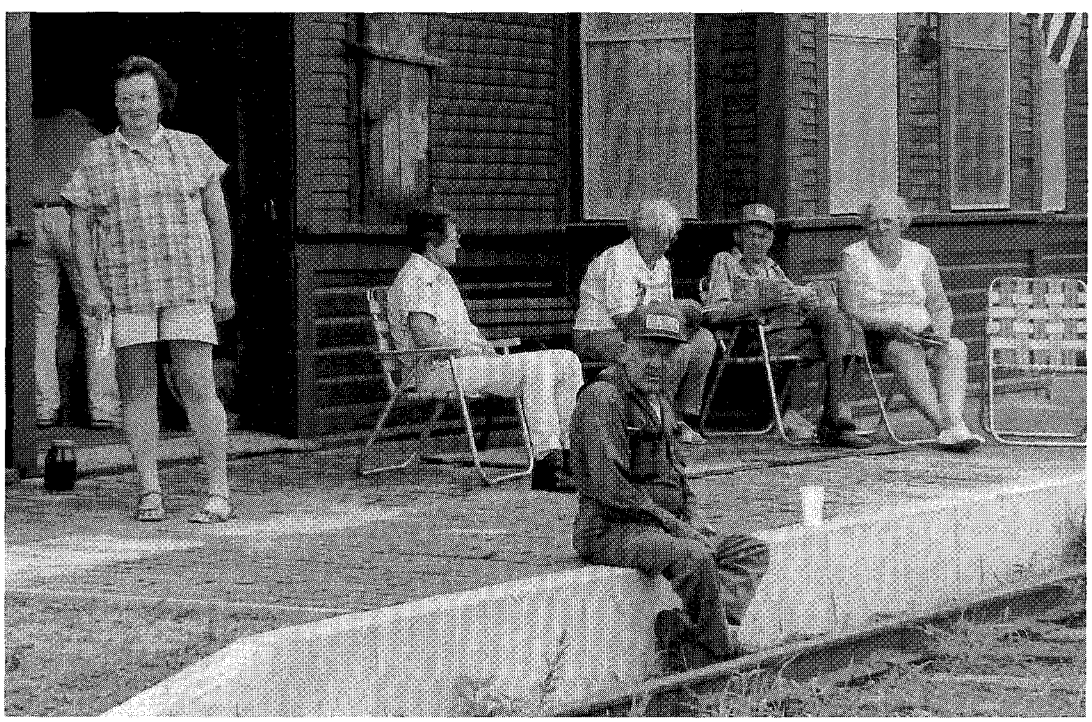
At a checkpoint in Mason City, Iowa, one of the observers, Marty Schenke, was standing at the timing table. As each car would come through, he would rapidly calculate the time difference from the scheduled start, and then compute the average speed of the car—all this in his head, not a calculator in sight. Curiosity got the better of me and I asked what he did for a living. "Oh, I do this all the time, I'm a U.S. Air Force Reserve Navigator." The observer corps certainly didn't lack for talent.

For the University of Oklahoma team, being in their home state was thrilling. In Ada, Oklahoma, one of the team members had his whole family come to visit him. It was heartwarming to see Grandma, Mom, Dad, Sis, and kids all visiting and looking with interest at the field of solar cells soaking up the sun. It was wonderful fun to be in Shawnee, Oklahoma, at the midday stop when the "Spirit of Oklahoma" team came in to wild cheers from the crowd. When Oklahoma reached the evening stop at Tulsa on the second day, local well-wishers catered an outdoor buffet

The Spectators

Scenes from the race combine to create a fascinating tour through middle America. With its spacious skies and rolling fields, there was no mistaking the route for New York City. It was pure country all the way—rural, green, and clean. Sitting in their front yards on chairs watching the parade of solar cars on country roads, wearing bib overalls and aprons and smiles of interest, the spectators were as much a show as the solar cars.

A group of neighbors, men and women, leaned on a tractor in a shed, waving. A young mother, sitting on a tractor near Ames, Iowa, held her baby daughter as Mankato State University drove by. Groups of team members took photos near oil wells in Oklahoma. A young girl stood in a fruit stand, smiling. A


In the small town of Turney, Missouri, people waited in the restored railroad station for solar cars to pass. The townsfolk had prepared "sun" tea (a jar is at the lady's feet) and cookies for the solar team members, but, unfortunately, the rain stopped most of the cars short of the town.

for the team complete with linen and china and a huge flower arrangement featuring sunflowers.

On the second day of the race, the Kauai Community College team developed a cracked weld in their titanium trailing arm. Rick Matsumura said they were near Shawnee, Oklahoma, way out in the countryside. As the friendly Hawaiians waited for the Oklahoma team to deliver epoxy to make temporary repairs, one of the local bystanders said he knew someone who had welded his aluminum ladder. A telephone call brought forth a retired aerospace worker who had titanium on hand at his shop. The crack was fixed in 10 minutes and the car was on its way. When exclaiming about their fantastic luck, Rick said, "That is why we carry Ti leaves in our car." The native Hawaiian plant leaves are used in ceremonials and are said to bring good luck.

At the evening stop in Cameron, Missouri, friendly townspeople prepared a meal for the teams and set up a farmers' market.

Observations Along the Way

There was a grand and colorful send-off on Sunday in Arlington, Texas for the start of the seven day race. The flags were flying in front of the Arlington Convention Center, and at 8:59 a.m. the official pace car, the electric powered GM Impact, was sent on its way by official starter John Agnello. The thirty-four solar cars soon followed, shepherded by their lead and following vehicles. As the cars sped out of Arlington and into the Texas countryside, the excitement of anticipation and uncertainty mounted. The fast cars were soon out in front. Others had mechanical or electrical problems and were stopped beside the highway with team members frantically working on them.

From Texas to Minnesota, the reception was enthusiastic. The competitors were given the opportunity to adopt a sister city on the race route. McGill University adopted Fort Scott, Kansas. When they arrived in Fort Scott, they were greeted with open arms, housed in private homes and presented with T-shirts, dinner, and even the key to the city. Canadian team member Pedro Gregorio said, "I haven't seen so much support and good will in a long time." At Fort Scott, to the cheers of the Sunrayce crowd, race organizer Richard King was formally inducted into a regiment of the U.S. Army horse dragoons by a giant, grey-bearded sergeant major, formally dressed in an authentic, gold trimmed, blue uniform of the last century.

Before noon on the fourth day, everyone knew rain was imminent when a solid black wall of heavy clouds appeared on the horizon. Tim Timmerman from the University of Minnesota said his team was south of Kansas City when the violent thunderstorm hit. They looked for space to get in out of the rain under freeway overpasses. Each one they came to had a solar car already parked underneath. Finally they just pulled off to the side of the freeway. A neighborhood man came by and asked if they wanted to use his garage three blocks off the road. They drove right to the garage

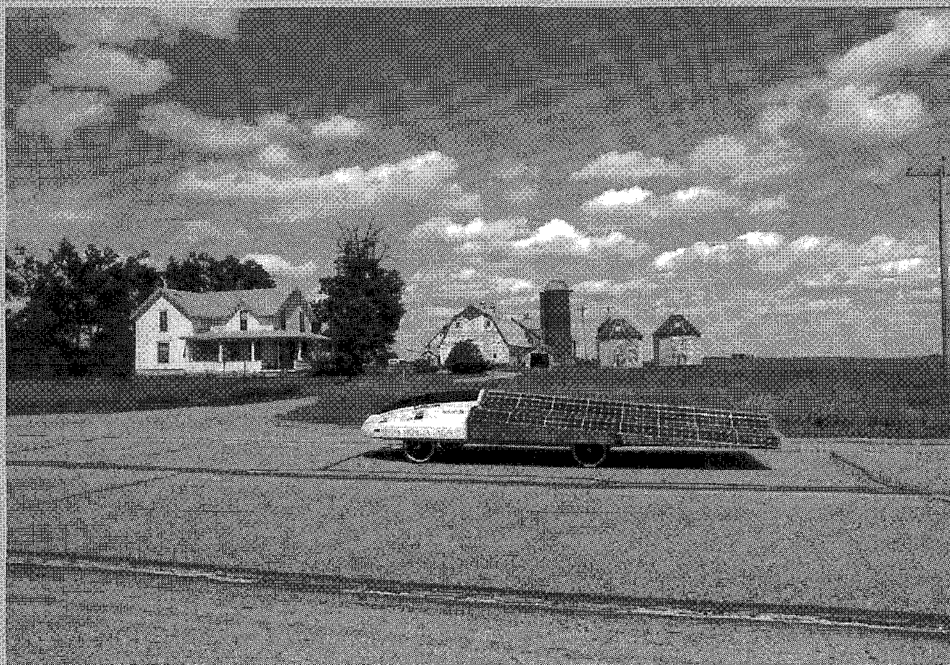
At the evening stop in Tulsa, well-wishers treated the Oklahoma team to an elegant catered buffet dinner complete with linen and silver.

and parked inside for the duration of the storm. It rained so hard that the beautiful streets of Kansas City were afloat. Workmen 15.24 meters (50 feet) down in a sewer line were trapped by the sudden rush of water. They were rescued after the storm.

The downpour caused headaches for some of the teams whose vehicles were less than waterproof. Puerto Rico reported that their car only had trouble when it rained. "We are bulletproof, not waterproof," said one team member. "The sun always shines in Puerto Rico."

North of Kansas City, in the small farm town of Turney, Missouri, Carl and Wilma Christopher had organized sun tea and snacks for the Sunrayce crews. The Christophers had the whole town waiting by their restored railroad station, but, unfortunately, the cars were having great difficulty in the rain, and not many of them made it as far as Turney. The fourth day ended in Cameron, Missouri, where the citizens had prepared a wonderful dinner. They set up booths, including a Farmers' Market.

The most hectic day of all was the fifth, which started in Cameron, Missouri, and finished in Des Moines, Iowa. In the



Western Michigan University's "Sun Seeker" contrasts the rural landscape with its modern profile.

morning, the vehicles and teams were spread out on the grassy lawns around Cameron High School. The solar arrays were out to gather up the sunshine. The team members were busy repairing, checking, and talking over strategy in the early morning. Off to the west the black clouds were moving in rapidly.

At first there were nervous glances. Then the human movements picked up speed as vehicles were put back together and all the tools, etc., were gathered up and moved toward the trailers. Lightning flashed, thunder roared, tarps came out, and people scurried for cover. The deluge began just one-half hour before the start! Everything that had been on the lawn disappeared into the vans and trailers. The six vehicles already lined up at the start—Los Angeles, George Washington, Michigan, Pomona, Stanford, Maryland, and Iowa, were surrounded by team members wearing slickers and holding tarps, plastic sheeting, umbrellas, and anything else they could find to keep the rain and occasional hailstones off their cars. Meanwhile, lightning and thunder filled the air and water ran down the streets. Everything was soaked.

Luckily, by 8:45 AM the sheets of water diminished to a misty drizzle. As teams shook off the tarps, starting flags were set up. The electric pace car was driven into position. Lightning still made bright streaks in the sky as the thunder receded in the distance. The countdown began and the solar cars were off. They were forced to chase the rain all day.

It continued to rain as the race moved into Iowa. Iowa State University, the local favorite, soon took the lead. People were out on every street corner under umbrellas and plastic sheets, urging them on. Cy, the Iowa State cardinal mascot, was painted on the front of their solar car and triggered cheers from the bystanders. Iowa State satisfied their fans by being the first to arrive in Des Moines at the end of the day.

In the end, Sunrayce 93 was about people: young, enthusiastic, and dedicated people. The spirit of the Sunrayce is epitomized by Cal Poly Pomona. Team captain Alan Redmond tells the story of his roommate, engineering student Dave Erikson. Dave was an intelligent, vital friend who was very active and liked to explore the limits of sports and life. When an announcement appeared on the bulletin board asking for interested students to build a solar car, Dave became very enthused and encouraged his friends to join in. He was a strong, dedicated team leader and was preparing to be the lead driver. With the project well along, Dave was killed in a speed skiing race. When Dave died, the team didn't know if they would continue. They decided a fitting memorial would be to finish the project. Pomona inscribed the initials DJE on the back of their vehicle and named the car "Intrepid" in honor of Dave's bold and fearless spirit.

Spectators view the solar cars soaking up the afternoon sun.

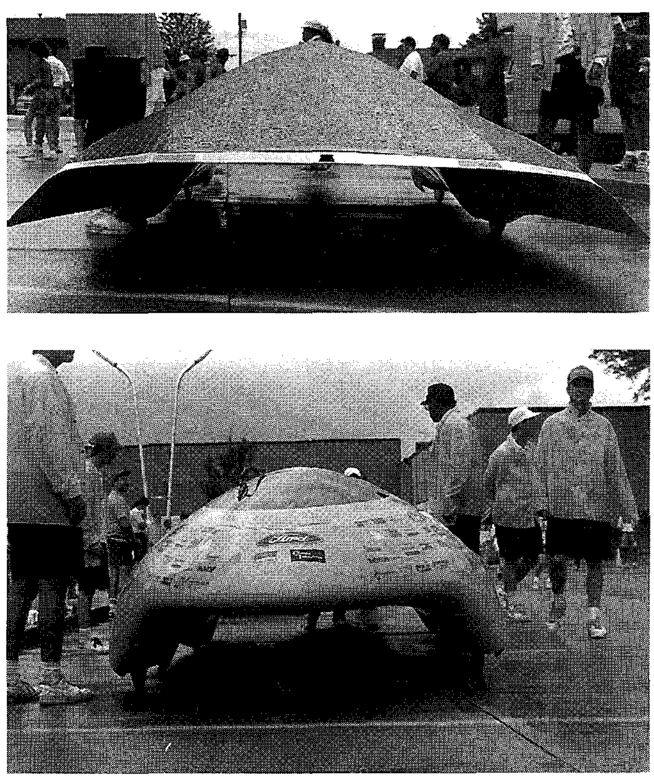
Chapter 5

Chassis Design and Construction

Solar car body and frame designs in Sunrayce 93 were of three general types—space frame plus body shell, carbon beams plus shell, and monocoque. The first is probably the easiest and quickest to build, and employs a tubing space frame which supports all of the load bearing components. The body shell is non-load bearing and removeable, and attaches to the frame. Examples of this type of construction include Michigan and CSU Los Angeles. The tubing frame material most often used was aluminum, although Kauai used titanium, UC Berkeley used carbon composite, and many others used chrome-moly steel tubing. The body shells were mostly of carbon/Nomex or aluminum honeycomb sandwich construction. Arizona State used a shell of fiberglass covered foam with foam bulkheads for support, materials that were inexpensive and readily available.

A variation of the tubing space frame—a riveted and glued aluminum box frame—was used by Virginia Tech. The body shell and suspension components were attached to the box frame. One of the big advantages of a tubing or box frame chassis is that the team can road test the vehicle before the body is completed. The University of Massachusetts, Lowell was able to pass the preliminary qualification tests by running laps with just the bare frame. This type of chassis can be very light. Oklahoma, which used an aluminum space frame with a carbon/aluminum honeycomb body shell, had the lightest car in the race at 103 kilograms (227 pounds) without batteries or driver. The CSU Los Angeles car weighed 178.3 kilograms (393 pounds), and Michigan's weighed 204 kilograms (450 pounds). See Table 1 for the weight and type of construction of all of the solar cars in Sunrayce 93.

Increased weight is not desirable since it causes higher rolling resistance, slower acceleration, and slower hill climbing speeds. For example, the addition of 45.4 kilograms (100 pounds) to a solar car would cause it to slow down about .6 kph (1 mph) on the level with no wind. Selection of high-strength lightweight materials and careful chassis design can save weight and increase speed. However, at times, adding weight to improve the aerodynamics or to enhance battery storage may pay off. In this case, an analysis of the effect of the added weight on the long-term average speed is required to justify any increase.



Front and rear views of the first place University of Michigan "Maize & Blue." The catamaran type chassis gives better solar array exposure in morning or afternoon sunlight when the solar angle is less than 90°.

The second chassis type utilizes carbon beams as a backbone or framework. Bulkheads are used as stiffeners and to support the body shell and components. The wheels and other components are mounted directly to the carbon beams or bulkheads. A non-load bearing belly pan is usually laminated to the beams, forming the under body. The solar panel and cockpit canopy form the upper body and may be detached quickly, leaving the interior open for maintenance. Examples of this chassis type include Pomona at 185.5 kilograms (409 pounds), George Washington at 163.7 kilograms (361 pounds), and Maryland at 192.8 kilograms (425 pounds). The advantage of this design is that the body shape can assume almost any desired form, without worrying about the space and strength limitations of a tubing frame. George Washington had the thinnest chassis in the race, a shape that would have been impractical to build using a tubing frame.

The third chassis type is commonly called monocoque, and employs a design in which the body shell itself supports all of the load bearing members. Stanford used a modified monocoque chassis with a unique 5 centimeter (2 inch) carbon/Nomex plank running down the centerline to stiffen the structure. The body shell itself supported the solar panel and Stanford added carbon bulkheads for mounting the front and rear suspension. They called it a "plank chassis". One advantage of the monocoque is it provides a spacious and uncluttered interior, with easy access to the equipment and the running gear. The chassis can also be relatively lightweight. Although Stanford's car was designed for two passengers, it raced with one in Sunrayce 93, and weighed only 199.6 kilograms (440 pounds) without driver compared to Michigan's 204 kilograms (450 pounds).

Of course, hybrids of the above frames are possible. Iowa State used a combination space frame/monocoque and others used a grid of carbon box beams to support the body shell and components.

To arrive at the net weight in Table 1, the battery weights listed were used. These were reported by each team and are not official weights. In looking at Table 1, the reported battery weight among the first six cars varied from a low of 108.9 kilograms (240 pounds) for CSU Los Angeles to a high of 154.2 kilograms (340 pounds) for

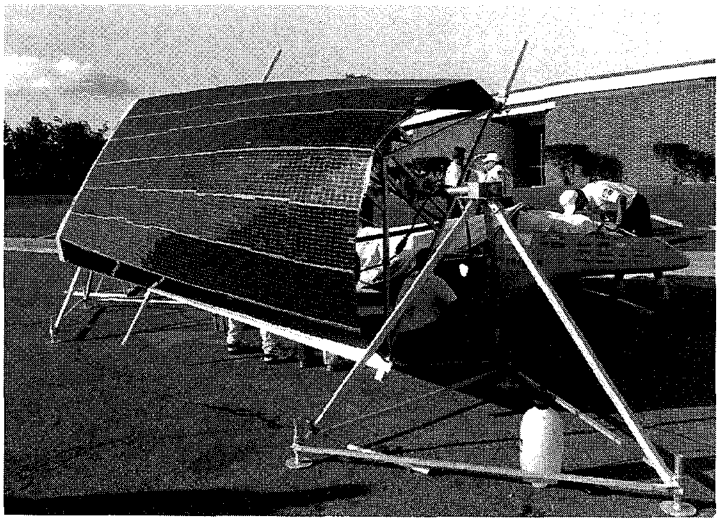
Michigan, even though the batteries all had about the same storage capacity in kWh. The wide variation in lead-acid battery weight for the same capacity means that battery selection should be optimized to determine whether the added weight would be compensated for by improved performance under race load conditions.

In analyzing Table 1, there is a good correlation between the race results and weight, since the best cars generally weigh less than average. But this correlation could have been due to other factors. To build a lightweight car normally requires attention to details such as body shape, materials, finish, and component selection. Although weight is important, other factors such as aerodynamics, power, and power efficiency influence the car speed far more than weight, and teams who did well in these design areas also did a good job of minimizing weight.

Table 1
Solar Car Weight Without Batteries or Driver

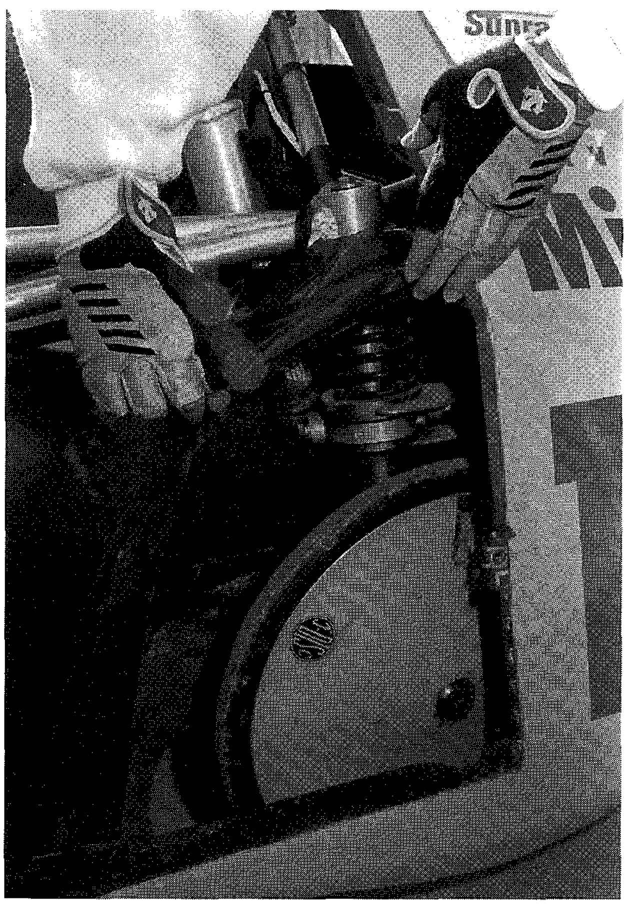
Car	Place	Construction	Battery Weight kg (lb)	Net Weight kg (lb)
Oklahoma	7	Frame/Shell	79 (175)	103 (227)
RIT	22	Frame/Shell	140 (310)	142 (314)
Clarkson	28	Monocoque	100 (220)	145 (320)
CSU Fresno	12	Frame/Shell	101 (223)	156 (344)
George Washington U	4	Carbon Beam	127 (280)	164 (361)
Drexel	17	Carbon Beam	104 (230)	171 (377)
CSU Los Angeles	3	Frame/Shell	109 (240)	178 (393)
U Texas Austin	32	Carbon Beam	127 (280)	181 (400)
Rose Hulman	15	Monocoque	116 (256)	182 (402)
Cal Poly Pomona	2	Carbon Beam	118 (260)	186 (409)
Colorado State	24	Monocoque	127 (280)	188 (414)
Kauai	9	Frame/Shell	112 (248)	191 (420)
Maryland	6	Carbon Beam	127 (280)	193 (425)
McGill	11	Frame/Shell	91 (200)	197 (435)
Stanford	5	Monocoque	150 (330)	200 (440)
Michigan	1	Frame/Shell	154 (340)	204 (450)
Puerto Rico	27	Frame/Shell	82 (180)	210 (462)
U Missouri Rolla	29	Frame/Shell	95 (210)	212 (468)
Mankato	16	Frame/Shell	109 (240)	215 (474)
W Michigan	18	Frame/Shell	108 (238)	232 (512)
Virginia Tech	20	Al Box Frame	127 (280)	233 (514)
U Mass Lowell	8	Frame/Shell	113 (250)	238 (525)
UC Berkeley	31	Frame/Shell	95 (210)	240 (529)
Ottawa	26	Frame/Shell	98 (217)	241 (532)
Arizona State	13	Frame/Shell	111 (245)	243 (536)
Queens	14	Frame/Shell	111 (244)	245 (541)
Auburn	25	Carbon Beam	109 (240)	248 (546)
Waterloo	33	Frame/Shell	114 (252)	248 (547)
Iowa State	10	Hybrid Fr./Mono.	150 (330)	250 (552)
U Missouri Columbia	19	Carbon Beam	159 (350)	268 (591)
Stark	23	Frame/Shell	135 (298)	284 (625)
Minnesota	21	Monocoque	80 (176)	297 (655)
New Mexico	34	Carbon Beam	104 (230)	300 (661)
Mercer	30	Carbon Beam	100 (220)	300 (662)
	Avg.		**114 (252)**	**214 (472)**

THE TOP CARS

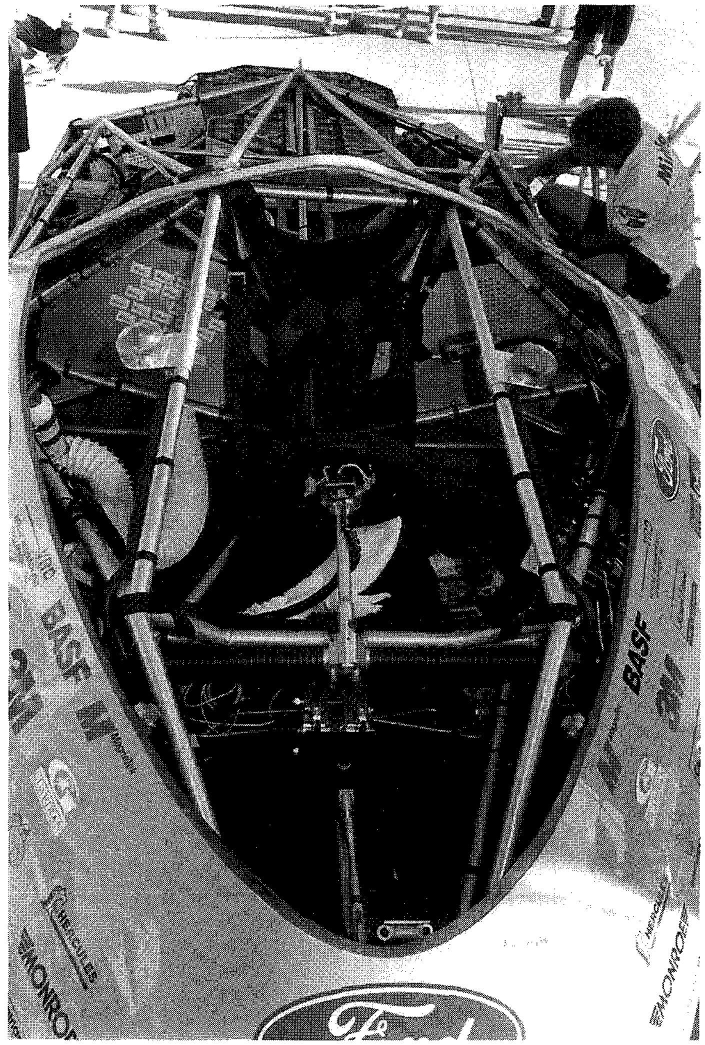


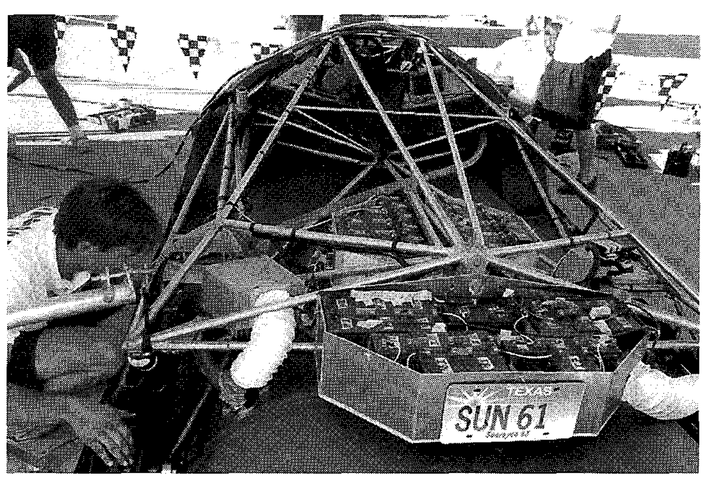
Michigan's solar panel, with eight facets, has a nearly continuous curvature, resulting in low aerodynamic drag.

#1 MICHIGAN



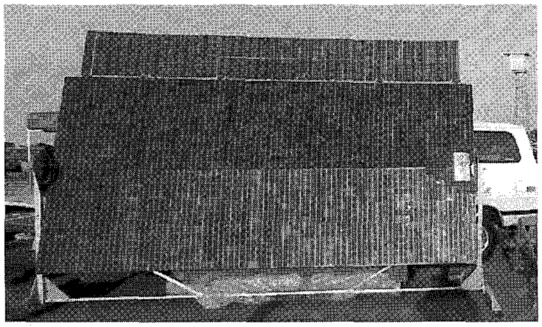
Michigan's front suspension. Many teams supported the wheels on vertical columns so that they could penetrate the body shell without enlarging the wheel wells.



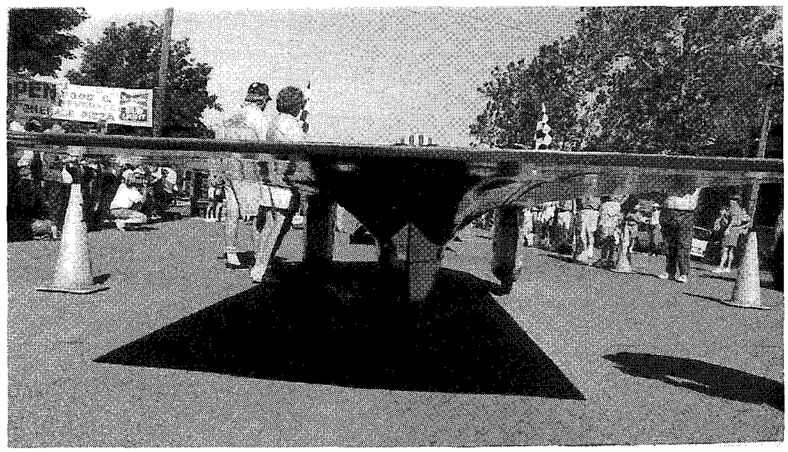


Front and rear views of Michigan's aluminum space frame. Michigan used IBM computer software to strategically place components in order to minimize the volume enclosed by the body shell.

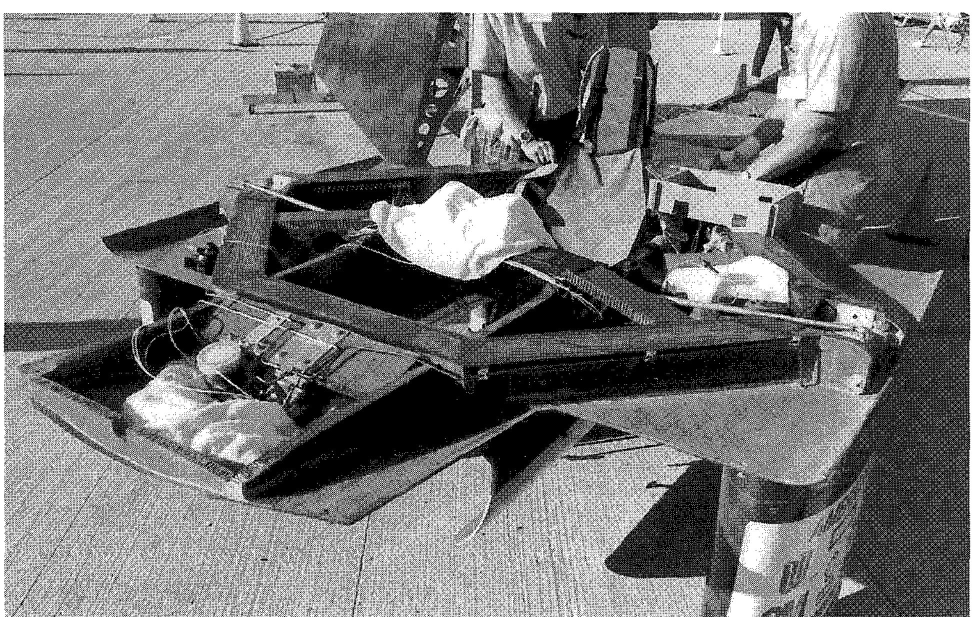
#2 CAL POLY POMONA



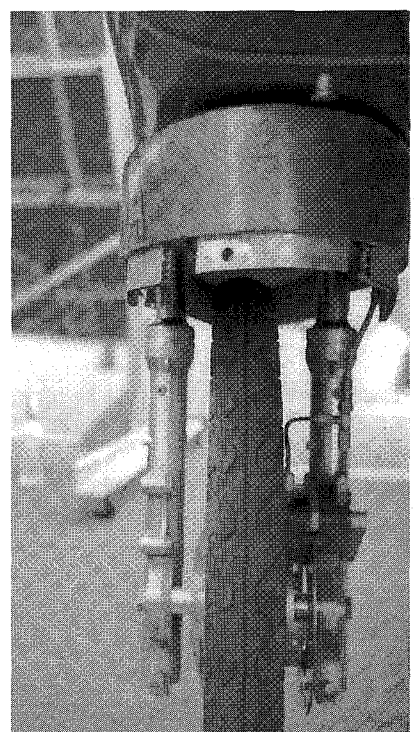
For charging the batteries when stationary, Pomona used a panel extension which mounts underneath the car when it is in motion.



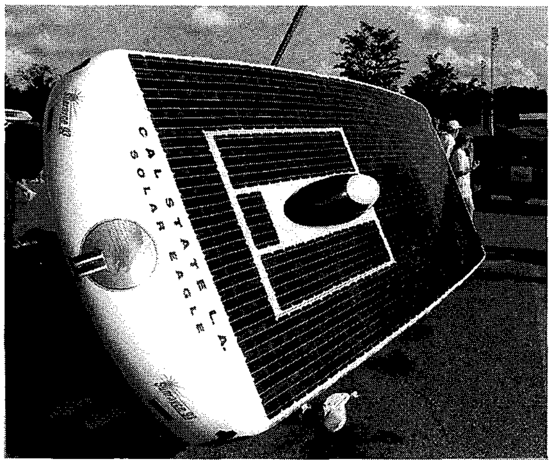
Front and rear views of second place Cal Poly Pomona's "Intrepid." The Intrepid was the only car with an exit hatch in the bottom. It allows the driver to get out of the car in less than five seconds.



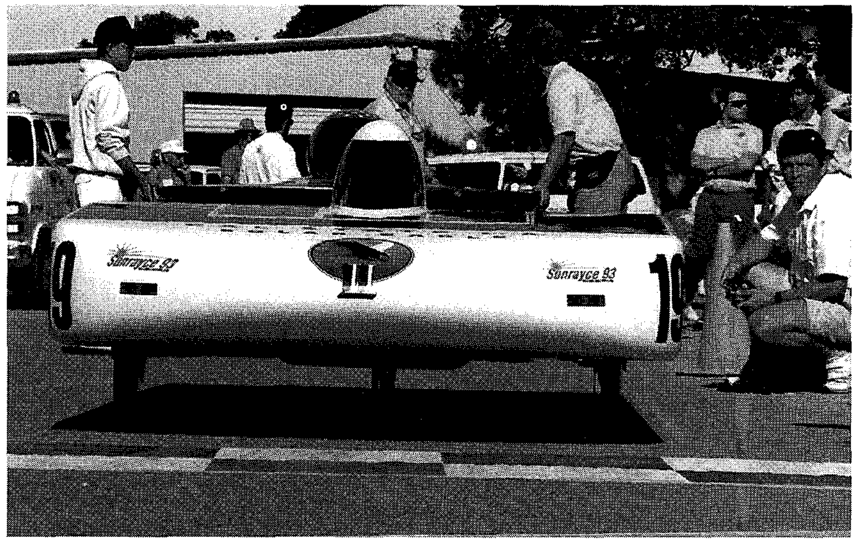
Front and rear views of Pomona's frame. Pomona used central carbon/Nomex sandwich beams with cross bulkheads to support the wheels and components.

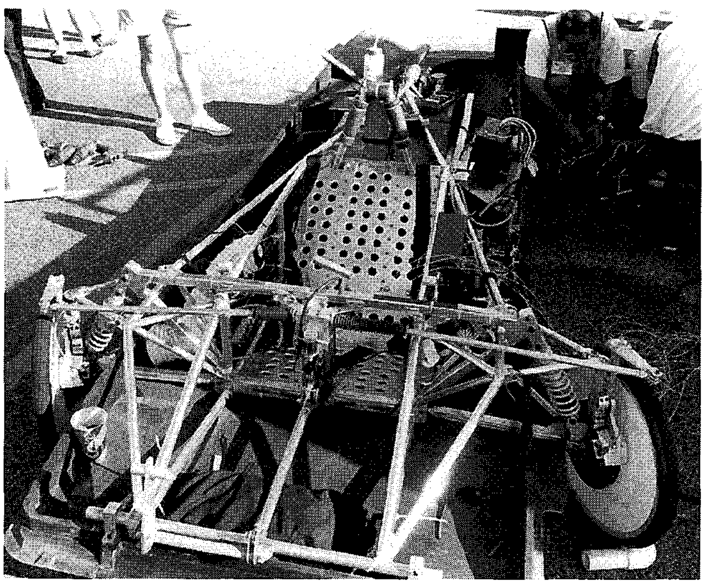


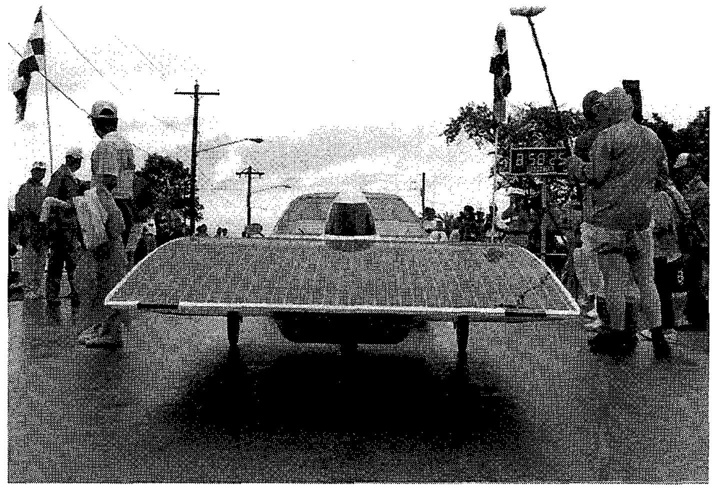
Pomona's front suspension and brakes are made from modified Honda motorcycle forks.



The Los Angeles solar panel completely surrounds the cockpit, which shortens the car by about 1 meter compared to conventional designs. Los Angeles used side solar panels to compensate for the solar cell area lost due to the cockpit canopy.

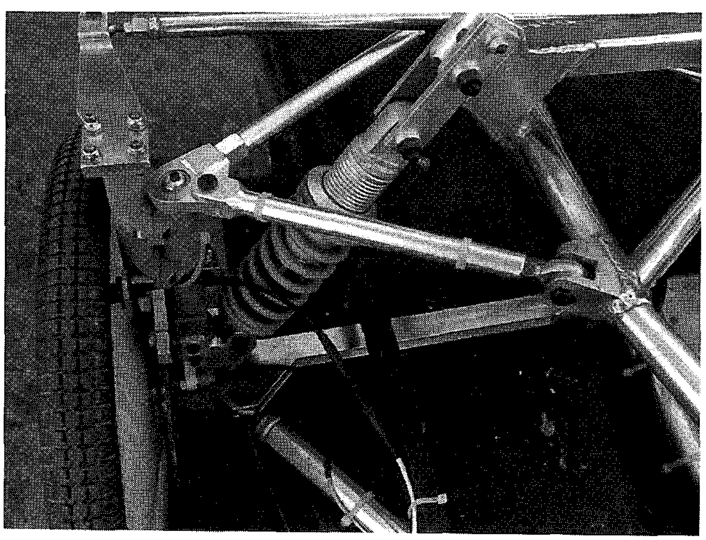




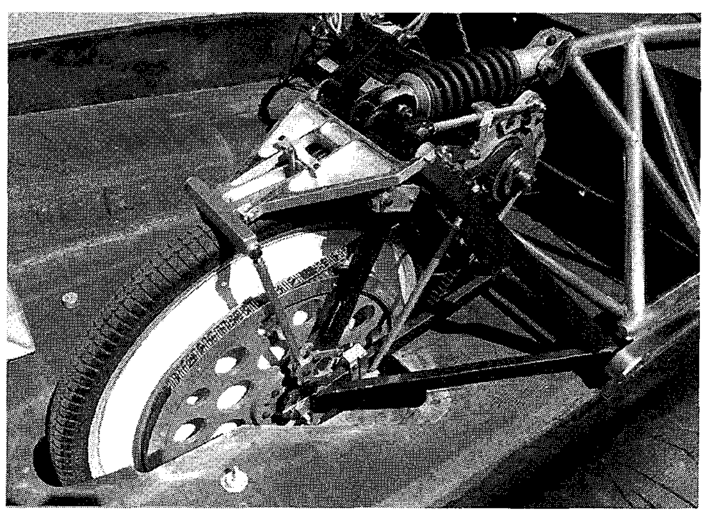


Front and rear views of the third place CSU Los Angeles "Solar Eagle," a wing shaped car.

#3 CSU LOS ANGELES

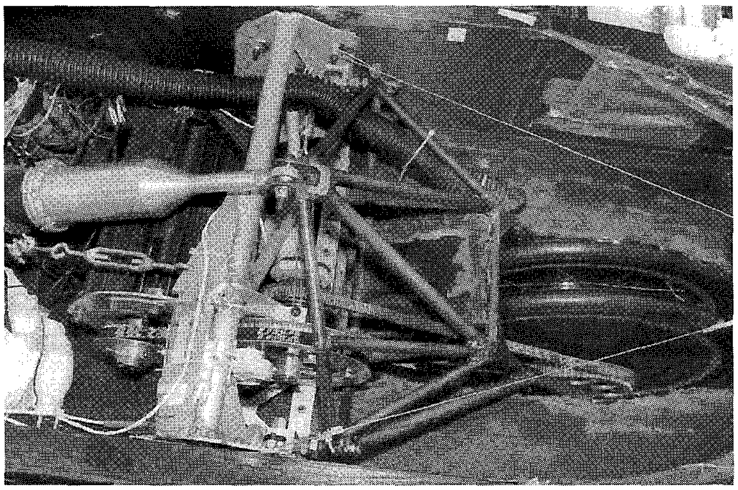


Los Angeles' aluminum tubular space frame and front suspension. Most of the cars used an unequal A-arm with a coil over shock on the front. This type of suspension can be designed to have nearly zero bump steer and zero scrub as the suspension deflects. A three-dimensional computer program was used to optimize the suspension.

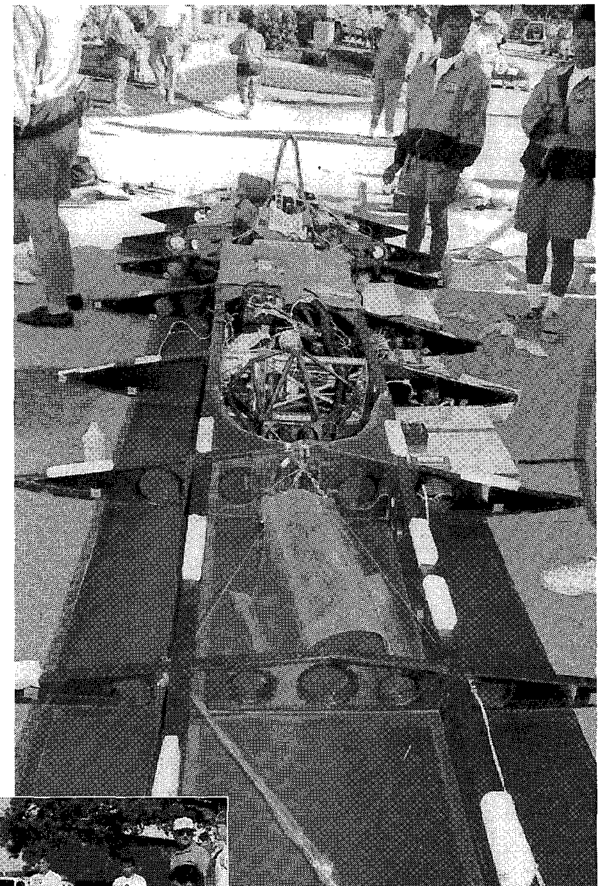


Los Angeles' rear suspension. The motor is directly mounted to the swing arm, a design which avoids coupling problems between a stationary motor and a live suspension. This scheme was used successfully by several teams. Apparently the motor is able to withstand the vibration and shock. A friction emergency brake on top of the tire can be used to hold the car when it is stopped.

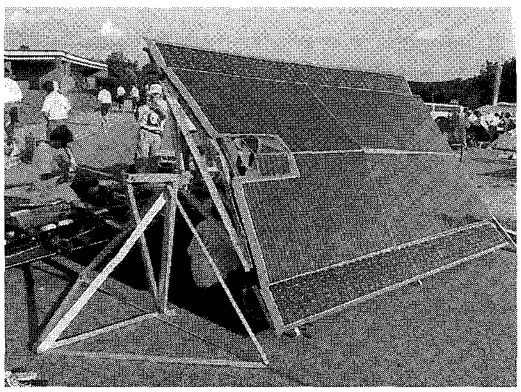
#4 GEORGE WASH



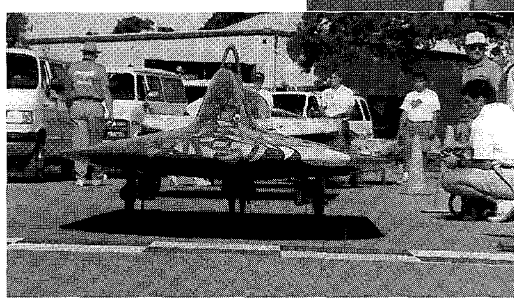
The George Washington rear suspension used a trailing arm with a stationary motor and a double reduction tooth belt drive system. The counter shaft is concentric with the swing arm axis. Perhaps due to axle and frame flex or a slight misalignment, George Washington had problems balancing the load between the twin rear tires. This caused uneven tire wear. Road camber might also have contributed to uneven wear with this design. Several teams used closely spaced twin rear wheels.



George Washington used carbon/foam/honeycomb sandwich beams and ribs to support the body shell and components.

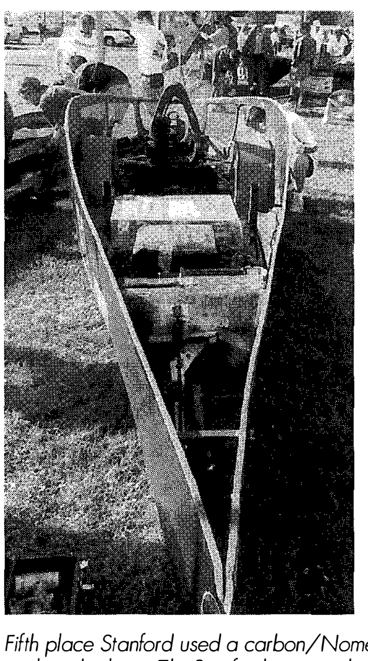


George Washington mounted two small solar panels under the car which were deployed in the evening to increase charge capacity.

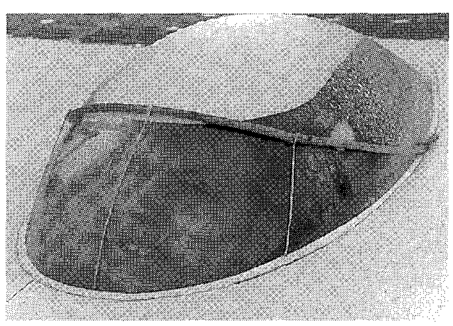


A front view of the fourth place George Washington "Sunforce". The Sunforce had the lowest frontal area of any car in the race, but the exposed, unstreamlined undercarriage created a higher air drag than one would expect from the sleek design. Like many teams, George Washington ran out of time before the race and was not able to completely finish streamlining the car.

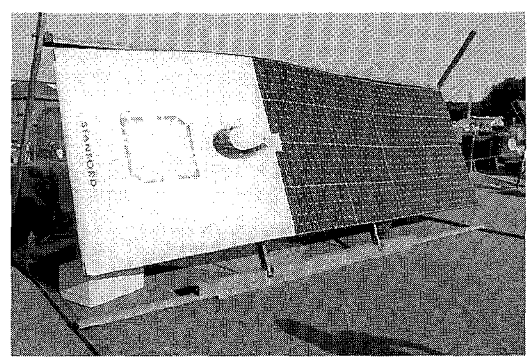
#5 STANFORD



Fifth place Stanford used a carbon/Nomex honeycomb monocoque-plank chassis with an enormous enclosed volume. The Stanford car was designed to carry two passengers for the World Solar Challenge in Australia. In spite of its size, the car was about average in weight.



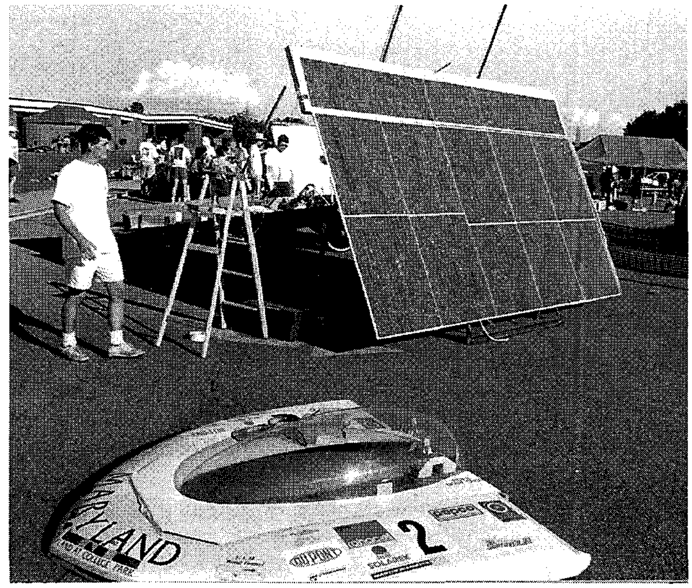
All cars in Sunrayce 93 had to have functional windshield wipers. Like many others, Stanford used stretched surgical rubber tubing with strings to pull the wiper down. It returns under its own power.



For the Sunrayce, all of the vehicles were single passenger and the projected area of the solar cells while running was limited to 8 square meters (86.4 square feet), so only 2/3 of Stanford's top surface is covered. For the 1993 World Solar Challenge in Australia, Stanford competed as a two person vehicle, which allowed them to mount solar cells over the entire top surface.

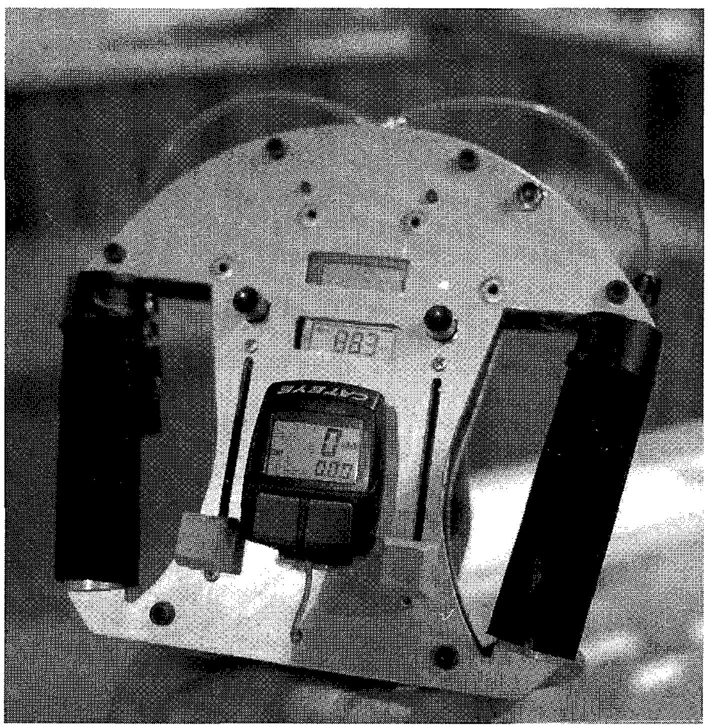
#6 MARYLAND

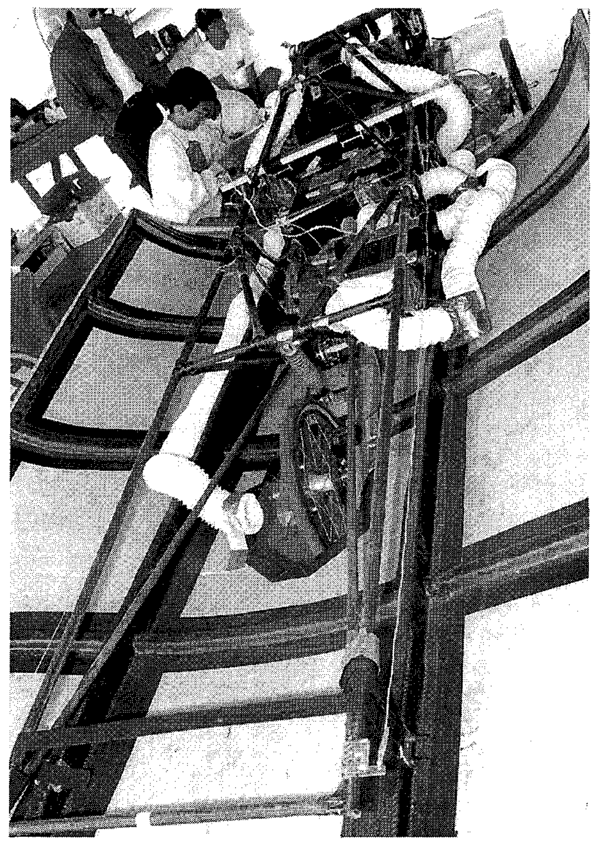
Like Pomona and George Washington, sixth place Maryland used a chassis with central carbon beams and cross bulkheads.

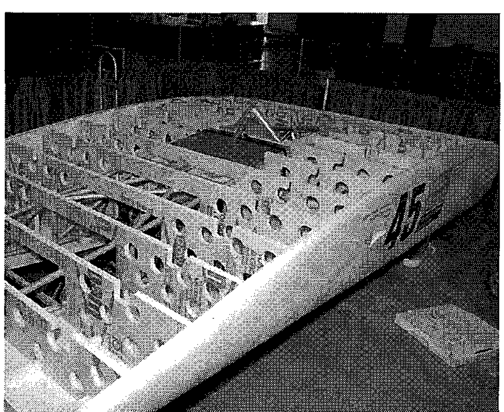


Maryland also used an extension on their panel for extra charge capacity when stationary.

OTHER COLLEGES







Arizona State used a simple aluminum tubing space frame, with a foam body structure which gave a smooth, unified aerodynamic shape. Although above average in weight, this construction was inexpensive and the chassis parts were readily available from local merchants.

Chapter 6

Analysis

Hypothetically, if several solar cars have equal aerodynamic drag, the same weight and comparable physical parameters, then the car that converts the sun's energy into mechanical power the most efficiently should win. However, racing often upsets this maxim. Sunrayce 93 was no exception. How does the potential performance of the leading cars compare with their actual performance? Before attempting to answer this question, let's look at the major factors influencing the speed of solar cars.

What Determines Solar Car Speed?

The factors that determine the average race speed of a solar car have been discussed in detail elsewhere (1), but a summary would be useful here.

Reliability. A car obviously can't maintain a high speed if it is continually stopped for repairs. This was the major cause of problems in Sunrayce 93. Over half of the cars suffered critical time losses due to repairs or system failures. Reliability can be improved by careful preparation, well-organized teamwork, and adequate pre-race practice. Even then, unexpected breakdowns can occur.

Net Solar Radiation Received. The most obvious factor, solar radiation, had a dramatic effect on Sunrayce 93. It is easy to demonstrate that the more available solar energy there is, the faster the cars can potentially go. The average solar radiation from 8 a.m. to 5 p.m. in Sunrayce 93 was 480 watts/meter^2 (44.6 watts/feet^2) and Michigan's winning average speed was 43.9 kph (27.3 mph). In 1990, Michigan entered the World Solar Challenge in Australia with a car whose performance characteristics were probably not as good as their Sunrayce 93 entry. In Australia, solar radiation averaged 730 w/m^2 (67.8 w/ft^2) and Michigan's average speed was 52.5 kph (32.6 mph), about 9.7 kph (6 mph) faster.

In Figure 1, the average daily solar radiation from 8 a.m. until 5 p.m. is plotted with the group average race speed for the first six cars (see Appendix 1 for solar data). The curve shapes are very similar. Figure 1 reinforces the point that the energy received determines solar car speed. Since there is a time lag between radiation intensity and battery charge accumulation, or power consumption and battery depletion, the curves are not precisely similar, but the correlation is still excellent.

Appendix 1 details the hourly average solar radiation, from 6 a.m. until 8 p.m., for locations along the route. Radiation varied widely, depending upon the cloud cover. The peak hourly average radiation between 1 and 2 p.m. during the race was 991 w/m^2 (92.1 w/ft^2) on day 6, and the minimum was 57 w/m^2 (5.3 w/ft^2) under the dark skies of day five. For the first three days, the weather favored cars that could complete the stage early, since there was more sunshine near the finish.

As Dean Raymond Landis of CSU Los Angeles put it, "Our blown motor controller on the first day delayed us for three hours and put us at a permanent disadvantage. Not only were we behind, but we had to drive through overcast skies, consuming power, while the leaders were charging their batteries in sunshine at the finish. The rich get richer and the poor get poorer." Being able to predict the weather along the route was a distinct advantage. Michigan had access to satellite cloud maps and gambled battery resources on the first day, knowing it was sunny at the finish. They recovered nearly a full battery charge by the next morning's start and led the race in the bargain.

Electrical and Mechanical Power Conversion Efficiency. The efficiency and size of the solar array and the electrical and mechanical system efficiency determine the net power that is available for propulsion. The greater the overall efficiency, the greater the amount of available power, and the higher the potential speed. Unfortunately, cost is a big factor—efficient solar cells, special motors, and other high-quality equipment are normally more expensive, so low budgets don't usually produce fast cars.

The solar cells used by the Sunrayce 93 competitors were of two varieties— monocrystalline silicon and multicrystalline silicon. The rated solar cell conversion efficiency was about 12.5% for multicrystaline silicon and varied from about 14% to 17% for monocrystalline silicon. Six manufacturers were used, BP Solar (monocrystalline—16 cars), Siemens Solar (monocrystalline—8 cars), AstroPower (monocrystalline—4 cars and multicrystalline—1 car), Solarex (multicrystal-

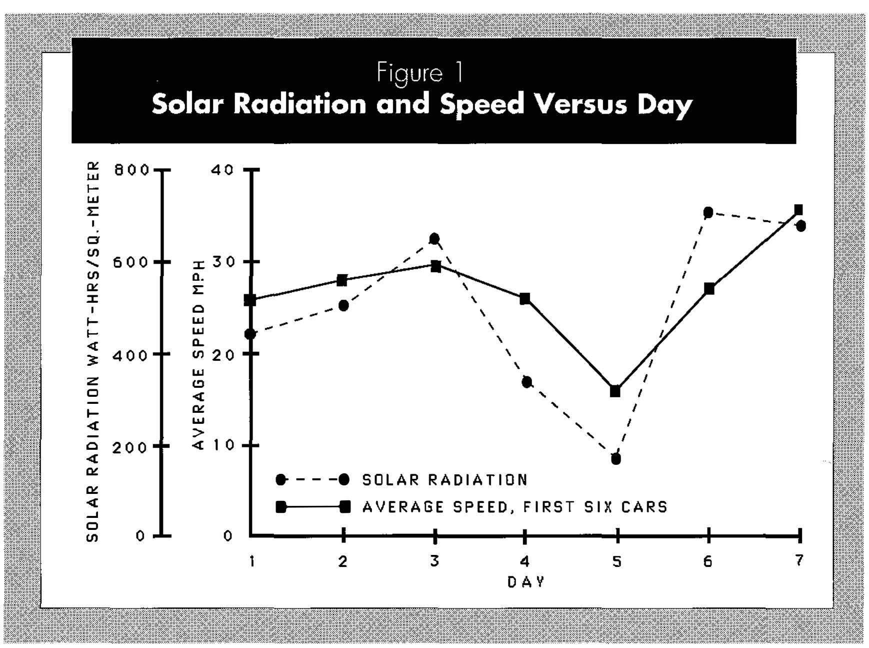


Figure 1
Solar Radiation and Speed Versus Day

line—2 cars), Kyocera (multicrystalline—2 cars), and ARCO Solar (monocrystalline—1 car). Solar cell characteristics are reviewed in references (1) and (2).

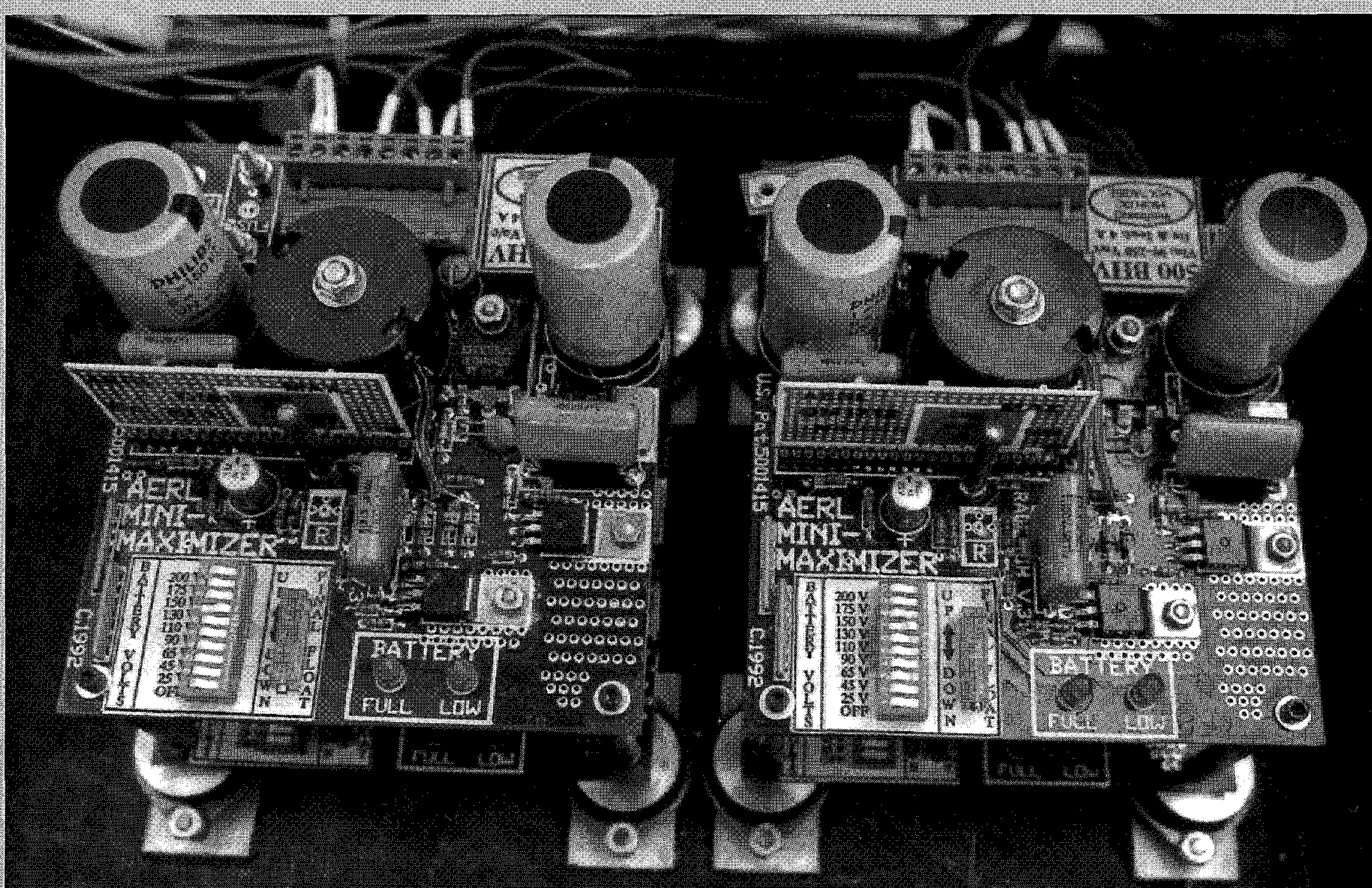
If cells are individually measured and the best are selected from a production lot, a gain in average panel efficiency may be possible. Michigan measured the efficiency of every cell they used, so they knew how their solar array would perform. They had 8000 cells tested at TRW at Redondo Beach, California, and the cells gave a mean of 16.3% single-cell efficiency. Even a small gain in panel output is significant. If cells can be selected that are17% efficient instead of 16%, this represents a 6% gain in useable energy.

In order to get maximum output from a solar panel, peak power point trackers are necessary to continually adjust the panel operating voltage to its optimum (1). If one module has a low output, it will draw down the rest of the panel to the same low level. One solution is to isolate sections of the panel and operate each section with peak power trackers to maximize yield. The most commonly used power trackers were manufactured by the Australian Energy Research Laboratories (AERL). These have losses of about 2%, but the automatic gain in panel efficiency far outweighs the small loss. Another commonly used design tool is to isolate sections of the panel with bypass diodes so that strings of cells with a low output will not draw down the rest of the module.

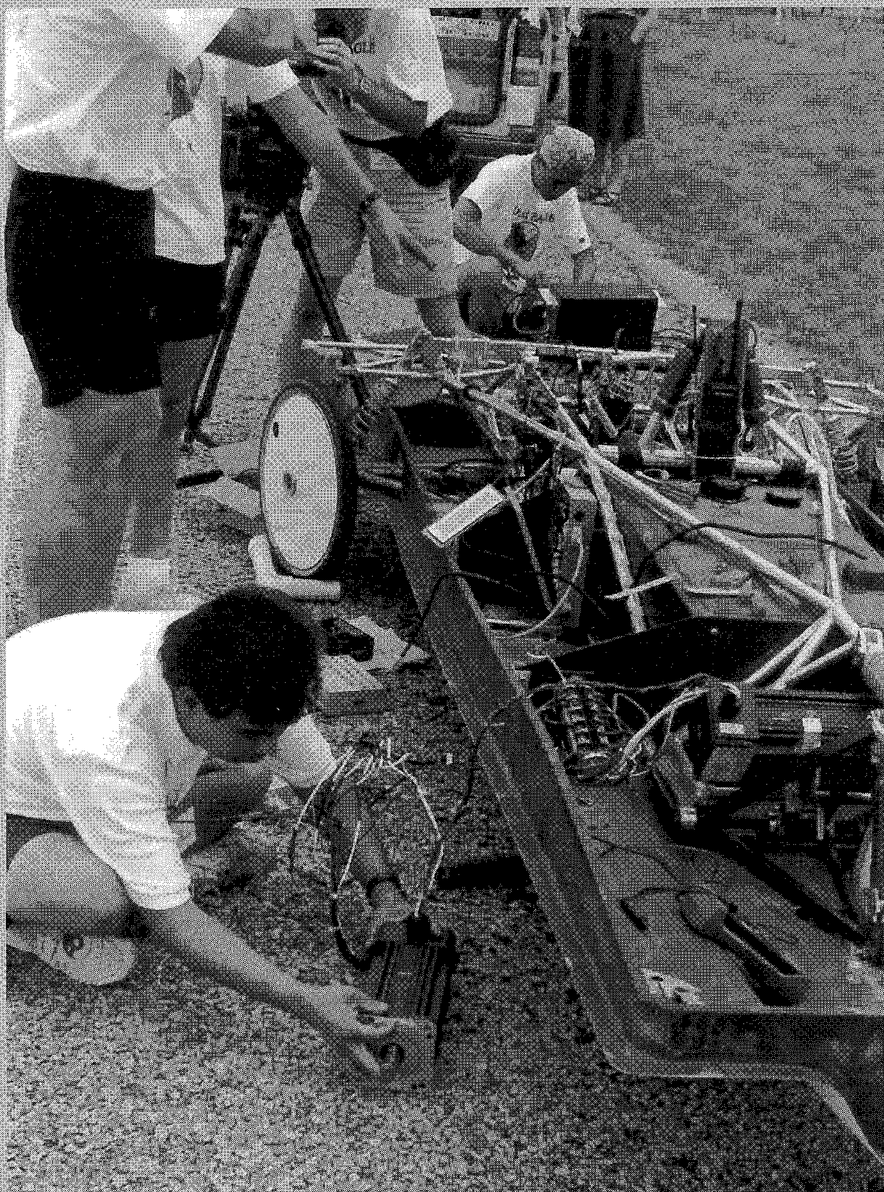
Another way of improving solar panel output is to closely space the cells for better area coverage. With special square cells that overlap, the packing density can exceed 97%, but the best area coverage in Sunrayce 93 was probably about 92%. By closer cell spacing, an additional 5% gain in power output would be possible. Some of the teams laminated a thin bora-silicate glass covering over the cells with an anti-reflective coating that can increase the radiation received by the solar cells. Also, a cell covering can protect the cells against rain or particle damage. Unfortunately, an ineffective cell cover can cut the solar panel output. One team removed the covering halfway though the race because the panel output was down.

Another important component is the motor. All but one of the teams used commercial brushless DC motors, with only Virginia Tech using a brush DC motor designed by the students. The combined efficiency of the motor, controller, and electronic power system at operating loads varied from about 86% to slightly more than 90%. Because of the wide range of load requirements, which include hill climbing, passing, and running under both sunny and cloudy skies, a solar car motor must have a higher power and torque capacity than it normally operates at and therefore usually runs below its peak efficiency. A motor rated at 94% peak efficiency normally operates at 90% efficiency or below, including motor control losses. The Sunrayce 93 cars employed motors from seven manufacturers, with the majority from Solectria (18 cars) and Uniq Mobility (11 cars). Michigan used a custom 1.8 kW rated MagnaTec motor which was bench tested at 93% efficiency under operating power levels.

Batteries can also be classified according to efficiency. The ratio of the 4 hour battery discharge rate to the 20 hour discharge rate



Peak power point trackers automatically adjust solar array voltage to the maximum power point when light conditions change. These compact trackers, made by the Australian Energy Research Laboratories, weigh about 1 pound each and are over 98% efficient.



On the first day, CSU Los Angeles lost three hours when their controller failed. They had to replace both the controller and motor.

should be as high as possible, to utilize the maximum stored energy. The reported discharge ratio for Michigan's Eagle Picher lead-acid batteries was 97%, while some batteries used in the race had a ratio below 80%. The 4 hour discharge rate is more realistic in modeling race battery demand, but the official regulations use the 20 hour rate in judging the capacity of the battery—thus the need for a ratio near 100%. The cycle efficiency (the ratio of recoverable stored energy during discharge to the energy input during charging) is also an important parameter. Cycle efficiency is above 80% for most rechargeable batteries.

Mechanical transmission systems were generally simple single gear reduction chain or tooth-belt drives. Straight chain drives have a mechanical efficiency of about 96% to 98%, so energy losses are minimal. Some teams used continuously variable transmissions (adjustable cone pulleys with a belt), but the energy losses in these transmissions proved to be excessive. Gear boxes with two speeds were also employed successfully. Simple gear reductions have low friction losses and are comparable to chain drives in efficiency. To avoid transmission losses entirely, a direct motor-wheel drive is also possible with the motor mounted in the wheel.

Aerodynamic Drag. The requirements for aerodynamically efficient solar cars are given in (1). In general, high aerodynamic efficiency is achieved by minimizing the drag coefficient and/or the frontal area. Fast solar cars have aerodynamic drag coefficients below 0.20, with some as low as 0.12. At typical race speeds of 56 kph (35 mph), aerodynamic drag is about 50% of the total resistance to motion, the rest being tire rolling resistance and bearing friction. The potential for improvement in aerodynamics is usually very significant. It is much easier and more economical to improve performance by changing body shape and finish than it is to purchase specially designed motors, tires, or other custom components.

Of the cars entered, 19 had efficient streamlined aerodynamic shapes with special attention paid to the small details such as wheel covers, wheel well ventilation control, surface finish, etc. Seven other cars could be classified as having adequate aerodynamics, with needed improvements such as wheel covers, minor shape changes, etc. Eight of the cars had poor aerodynamics which would require a complete redesign. These cars were uniformly slower than average. At least one of the cars might have been in the top ten with better aerodynamics. The irony is that normally it takes about the same amount of work to build an efficient aerodynamic shape as it does a poor one.

The most common contributors to high aerodynamic drag were multifaceted flat solar panel surfaces that cause significant flow separation. Because flat solar panels are so simple to build, they are tempting to use, but they must be oriented parallel to flow with rounded leading transitional surfaces and thin trailing edges to avoid excessive drag. Since airflow is always three dimensional, two dimensional planes are difficult to incorporate into a body shape.

Car Weight. Reducing the weight of the vehicle increases acceleration and hill climbing speeds and lowers tire rolling resistance. The weights of Sunrayce 93 cars varied from a low of 205 kilograms (452 pounds) without driver (Oklahoma), to a high of 427 kg (941 lb) (U Missouri—Columbia) with a mean of 329 kg (726 lb). Because the race rules required the teams to use lead-acid batteries, the batteries contributed significantly to the overall weight of the cars. On average, the batteries accounted for about 35% of the car weight without the driver. The fastest cars used advanced composite materials and construction techniques to achieve the lowest possible structural weight.

Tire Rolling Resistance. In general, low friction tires have low weight, thin walls, and thin smooth tread. They use high air pressure and are made of resilient, elastic materials. Most of the Sunrayce 93 entrants employed bicycle tires. In spite of their light weight, bicycle tires are generally rugged enough for solar car racing, and they have about half the rolling resistance of motorcycle or automobile tires. Because of their narrow profile, they also have less air drag, and they weigh less. The most common tire in the Sunrayce was a 50.8 x 4.4 centimeter (20 x 1.75 inch) tire with slick tread. Tire pressures ranged from 6.35 to 8.44 kg/cm² (90 to 120 psi). Also common were 66 centimeter (26 inch) wheels with slick mountain or city bike tires.

A few teams used very unusual tires. Oklahoma, for instance, ran with 27 inch x 20 mm (68.6 cm x .79 in) tubular bicycle racing tires inflated to 10.55 kg/cm² (150 psi). Except for problems with spoke breakage and occasional flats, the wheels and tires performed satisfactorily and probably had the lowest rolling resistance of any used in the race.

Michigan and George Washington used 43.1 cm x 3.2 cm (17 x 1-1/4 inch) tires made by Wolber (a division of Michelin). This uncommon bicycle tire size was originally developed by the Dunlap Company for Alex Moulton of England. Standard ribbed Moulton/Wolber tires have a very low rolling resistance, considering their small diameter. In 1987, with Moulton's permission, Wolber developed several tires with slick tread for the General Motors Sunraycer. The tire molds still belong to Moulton.

Michigan was able to obtain special Moulton/Wolber tires from Michelin formulated with a harder rubber compound. These custom tires, when used with a liquid puncture sealant, will wear several hundred miles without failure. Unfortunately, George Washington could only obtain normal commercial Moulton slicks, designed for light bicycle service, and punctures or pinch flats proved to be a huge problem. George Washington suffered 21 flat tires during the race and probably lost third place because of tire problems.

CSU Los Angeles made an interesting field measurement of power consumption at an unspecified fixed speed. Their measurements showed that by raising the tire pressure from 6.35 to 7.73 kg/cm² (90 psi to 110 psi), the power consumption dropped 5%. Incidentally, the tire size is an approximate nominal designation and actual outside diameters will vary depending upon the tire type.

Technical Regulations — Development, Interpretation, and Loopholes

The official technical regulations are often overlooked as an important influence on solar car speed and efficiency. Every solar car competition has a set of technical regulations that are established to promote safety and to define limitations on certain factors that affect performance. For example, in the World Solar Challenge and in the U.S. Sunrayce, battery capacity is limited to five kilowatt-hours and the solar array must fit with a box 2 meters wide, 4 meters long, and 1.6 meters high (6.6 feet wide, 13 feet long, and 5.3 feet high). Sunrayce regulations further limit the choice of batteries to lead-acid and the solar cells to terrestrial grade costing no more than $10 per watt.

Some regulations established for safety reasons also affect performance. For example, the one meter (3.3 foot) minimum height for Sunrayce 93, which was intended to ensure a solar car's visibility to other drivers, restricted the reduction of aerodynamic drag. The World Solar Challenge regulation that requires a minimum height of 70 cm for the driver's eyes to assure that driving visibility is adequate, has the same effect on aerodynamics.

Technical regulations evolve as experience provides new knowledge and insight. The desire to de-emphasize the funding level difference between teams led to the limitations Sunrayce 93 placed on the battery and solar cell type. No matter how carefully regulations are written, each event reveals some weakness in the regulations that is exploited by one or more teams to gain a performance advantage.

Some Sunrayce 93 competitors sought to gain better aerodynamic performance by meeting the minimum height of 1 meter (3.3 ft)

A storm grating outside of Tulsa, Oklahoma destroyed several wheels and damaged several suspensions. The University of Oklahoma's wheel, shown above, collapsed after hitting the grating, even though the tire was not damaged.

with a 15 or 20 cm (6 or 8 inch) fin on top of the canopy, thus voiding the regulation's intent of insuring visibility. Future regulations for this purpose will rely on minimum driver eye height.

In the 1990 Sunrayce, one team took advantage of ambiguity in the regulation on solar panel size. Their panel fit within the 2 x 4 x 1.6 meter (6.6 x 13 x 5.3 foot) box on the diagonal, front to rear, but when located on the solar car in running position, it was longer than the 4 meters (13 feet) intended. The 1993 rules specified that the panel must fit within the box while in running position. In Sunrayce 93, several teams using essentially flat horizontal solar arrays had narrow supplementary arrays attached underneath the body. These arrays could add a little to solar collection during running, but some teams didn't even have them connected while they were moving. During stationary charging periods, however, the teams deployed these arrays to create a larger primary panel tilted to capture the maximum solar energy. These wider panels still fit within the box on the diagonal, and since there was no limitation on box orientation during stationary charging, they were deemed to be in compliance with the rules. For the next event, the organizers must decide whether they will let this interpretation stand, or will amend the regulations to prohibit such solar panel reconfiguration.

Sunrayce 93 regulations required that the solar cars be impounded each evening at a certain time. No work was allowed on the solar car during the impound period. Originally, this rule was intended to ensure that the team members got some rest during the grueling 11 day event. However, the regulation did not prohibit working on spare parts. For example, a controller that failed and was replaced during the day could be repaired at any hour, frustrating the original intent.

In 1993, considerable dispute arose over what constituted a complete solar car for the purposes of impound. Could a car be impounded without a motor or controller or even a solar array? Some hasty and poorly conceived modifications were made to the regulations during the event to deal with this problem. Because one team worked on their solar array out of impound, another assumed that the impound rule was not being enforced, and worked on their entire car until the early morning hours, an infraction that carried a very heavy penalty. Because of the confusion, officials levied a much lighter penalty on the offending team than the regulations called for.

Regulations must be carefully prepared. They must contain the absolute minimum that is required to keep the event safe and fair. Then the regulations must be enforced. Written permission from the Race Director should be required to breech any regulation without penalty. Specific penalties for rule infraction should not be stated in the regulations, but should be left to the discretion of officials based on the particular situation. Most important, changes to the regulations during the event should be avoided if at all possible. Hasty changes almost always create new disputes and problems.

Common Mechanical and Electrical Problems

Many of the problems experienced by the teams during the race are listed in the data sheets of Appendix 3. Also, Stanford compiled a list of solar car problems which is detailed in Appendix 2. What follows here are some of the most commonly mentioned difficulties during the race.

Electrical Component Failures. Five cars had motor controllers that failed, several of which led to damaged motors. Luckily, replacements were available. A number of teams complained of bad instrumentation in their cars. The amp-hour meters used to monitor battery charge seemed especially susceptible to problems. This caused the batteries to be unintentionally drained, leading to a permanent power debt. Some teams had to replace batteries because of instrument failure. Broken connections, grounded wires, shorts in the solar panels, loose electrical connections, and other vibration-induced faults were common and caused significant time losses.

The frames and bodies of solar cars are normally highly conductive, since they are often constructed of metal or carbon fiber. Because of this, electrical wiring and components have to be carefully isolated from the frame and shock-protected against vibration. Solar cells are particularly sensitive. Even Michigan had to replace 3 damaged cells, and Mercer broke 43 cells due to a canopy latch failure which caused the panel to fly off. Water-induced electrical shorts were also common because of the prodigious rain. Many cars did not have waterproofed solar arrays or bodies, which caused real problems during the violent thundershowers that racers encountered.

Mechanical breakage. Traveling over railroad tracks and rough roads caused numerous broken suspensions, bent frames, broken shocks, collapsed wheel rims, broken spokes, broken steering, and other problems. To avoid this, good communication with the occupants of the lead car is essential, because they can warn of an approaching hazard. Also, scouting the road in advance and marking trouble spots on the route sheet helps. Broken suspensions caused five cars as much as a day's delay. On cars with a large flat side area such as Stanford's and Oklahoma's, the huge side force from cross winds caused wheel and tire failures. Stanford had two rear blowouts that spun the car around almost 180°.

Frequent spoke breakage was a minor plague. Broken spokes can be avoided in several ways, including installing more spokes, using heavier gage spokes, using wider hub flanges, and setting spoke tension uniformly to the proper stress. It takes an expert wheel builder to true wheels and tension spokes properly.

During scrutineering, all of the fasteners associated with the critical chassis, suspension, and steering components were inspected by officials to ensure that they had lock washers, lock nuts, or Locktite and that the threads were fully engaged. This was the most common problem during mechanical inspection, and the faults had to be corrected before the cars were passed. Even so, vibration frequently caused nuts, screws, and fasteners to work loose during the race. Adequate road testing before the race is the best strategy for detecting and correcting such unforeseen failures.

Battery Problems. It is important to have instrumentation that accurately determines the battery charge, including a backup system. Fresno drained their batteries on the first day because of faulty instrumentation. During the race, batteries were often drawn down to voltages below their rated minimum, especially on the fifth and sixth days. This deep cycling often led to battery damage, even among the leaders. A common problem was cells that weren't balanced in voltage and capacity, causing excess battery drain. Cells in a battery pack have to be carefully matched.

Almost every one of the 34 cars in the race had significant failures. Conditions were tough enough that it seemed to be a race of survival. Luckily, most of the wounds were healed by the final day, and all of the cars crossed the finish line under their own power.

Potential Versus Actual Performance

In the following analysis, we use the data provided by each of the competitors to predict the potential speed of the first six vehicles. The basic information is contained in the data sheets of Appendix 3. The following equation describes the mechanical power necessary to overcome the drag forces of a solar car (1):

$$P = WV(\sin(\arctan G) + C_{rr1}\cos(\arctan G)) + NC_{rr2}V^2 + 1/2C_dA\rho V(V+V_w)^2$$

where P is the power in watts, W is the total weight including driver, C_{rr1} is the rolling resistance coefficient, G is the fractional slope (the rise divided by the horizontal distance), N is the number of wheels, C_{rr2} is a factor defining the variation of rolling resistance with velocity, V is the car velocity, C_d is the aerodynamic drag coefficient, A is the frontal area, r is the air density (a value of 1.2 kg per cubic meter was used in all calculations), and V_w is the velocity of a headwind or tailwind with the sign being positive for a headwind.

The first term in this equation gives the power due to gravity in ascending or descending. The sign of G is positive uphill and negative downhill. The second term gives the power consumed by tire rolling resistance. The third combines the drag due to wheel bearing and windage losses as well as the velocity-dependent losses in the tires (1) and the fourth is the power required to overcome the aerodynamic drag of the vehicle.

For simplicity, we used a value of 0.0502 for C_{rr2} for all of the calculations. This value was measured in tire tests by General Motors in 1987 (1).

Using actual performance data, wind tunnel data or estimates provided by the competitors for the first six vehicles, the factors in the equation are shown in Table 1.

The tire rolling resistance coefficient (C_{rr1}) listed above is an estimate from previous measurements of tires on an asphalt surface (1). The drag area (C_dA) was estimated from road power data given by each team, or from wind tunnel data, whichever seemed the most reasonable.

Figure 2 is a performance curve provided by CSU Los Angeles that was used to compute C_dA for their car (0.16 m^2). The vehicle with the lowest reported aerodynamic drag in the race was George Washington (C_dA = 0.12 m^2). They had a razor-thin body with only 0.6 m^2 (6.5 ft^2) frontal area that was coupled with an efficient airfoil body shape. They reportedly had about half the aerodynamic drag of the Stanford or Maryland cars. However, their aerodynamic drag data is probably optimistic, because they had to install an exposed roll bar to meet the minimum height requirements, and their rough, sharp-edged wheel structure was exposed to airflow. Still, if they had installed wheel fairings, and had been able to use an internal roll bar, George Washington would have had a very low-drag car.

Assuming that the efficiency of the power electronics system is 98%, and the efficiency of the mechanical drive is 97%, for 1000 watts input to the motor, the mechanical power available for propulsion would be 1000 x Motor Efficiency x 0.98 x 0.97. For example, for 1000 watts input, CSU Los Angeles would have 1000 x 0.90 x 0.98 x 0.97 = 856 watts available for propulsion.

Using the equation and the above data, the estimated speed of the cars on 1000 watts input to the motor is shown in Table 1. According to their reported performance data, the potential speed of the cars on 1000 watts input, would be George Washington 64 kph (40 mph), Michigan 61 kph (38 mph), Los Angeles 61 kph (38 mph), Pomona 58 kph (36 mph), Maryland 55 kph (34 mph), and Stanford 53 kph (33 mph). According to these calculations, the only car that didn't perform up to its potential was George Washington. To determine why, we should examine several factors.

When the cars were running, Michigan and Los Angeles—because of their side solar panel area—should have intercepted more solar radiation than the cars with flat, horizontal panels. George Washington, Maryland, and Pomona, however, compensated for this by carrying panels on their vehicles that could be extended for stationary charging, as we mentioned earlier. Michigan, Los Angeles, and Stanford did not have extended panels. According to the teams' reported data, the performance of the solar panels for the first four cars was approximately the same. Solar panel output, therefore, was probably not a contributing factor to George Washington's lower than anticipated finish.

Basic efficiency of the powertrain and batteries, however, was an important consideration. Michigan probably had the most efficient

Table 1
Performance Characteristics of Sunrayce Leaders

Car	Weight kg (lb)	C_dA m^2 (ft^2)	C_{rr1}	C_{rr2}	Motor Eff. %	Speed on 1000w
Michigan	438 (966)	0.133 (1.44)	.0060	.0502	93%	38 mph (61 kph)
Cal Poly Pomona	384 (847)	0.19 (2.05)	.0055	.0502	90%	36 mph (58 kph)
CSU Los Angeles	367 (804)	0.16 (1.73)	.0055	.0502	90%	38 mph (61 kph)
George Washington	371 (818)	0.12 (1.30)	.0060	.0502	89%	40 mph (64 kph)
Stanford	430 (948)	0.25 (2.70)	.0055	.0502	92%	33 mph (53 kph)
Maryland	400 (882)	0.20 (2.16)	.0055	.0502	85%	34 mph (55 kph)

Figure 2
CSU Los Angeles Performance Data

power system of the top four and George Washington had the least efficient. This inefficiency coupled with tire problems and the likelihood that George Washington's actual drag coefficient was higher than estimated explains their lower than expected finish. If the reported data are accurate, the other cars in the top six finished approximately in the order of their potential speed.

From the above discussion, we can draw some conclusions about the leading cars. Michigan finished day five under their own power not because of superior aerodynamics, structure, mechanics, or speed, but because they had several other factors in their favor. Weight was not one of them, because at 438 kg (963.6 lb) with driver, the Michigan car weighed more than two-thirds of the cars in the race, and was the heaviest of the top six. However, they probably had the best weather prediction of any of the teams, and the best battery utilization strategy. Michigan seemed to be racing against themselves and not against others.

Second, their power drive system and solar panel were probably the most efficient in the race. Third, they had practiced for 4827 kilometers (3000 miles) and nearly all of their short-term faults were corrected. Michigan's crew was very thorough and well-organized, although that was also true of many of the other teams. Incidentally, because of a faulty amp-hour meter, Michigan didn't think they would finish day five, and, when they did, the deep battery draw-down caused minor damage to the batteries.

Pomona took second because of a superbly designed car that was nearly fault-free. The Pomona car was both fast and reliable, and they had almost no down time. If they had conserved their batteries a little more on day 4, they might have finished day five and improved their final time somewhat, but that is hindsight. Considering the intense competition in the first part of the race between Pomona, Michigan, George Washington, and Los Angeles, all of these cars had dangerously low batteries at the end of day four.

The major problem with the CSU Los Angeles vehicle was the faulty controller and power switch. Aside from that, their car was meticulously designed and constructed and very fast. On days one and two, the motor unexpectedly switched into reverse several times. By the time they corrected the problem, they were too far behind to catch up. Without electrical problems, they had the speed to win the race, or at least to come very close. Ironically, Los Angeles had driven the car 1931 kilometers (1200 miles) without a controller failure, so practice is not the answer to all problems.

George Washington also had reliability problems that slowed them down. Without the ground shorts, latent component failures, broken suspension, flat tires, bent wheels, etc. that plagued them, they could have remained in third place. As one of their competitors said, "113 kilometers (70 miles) of practice just isn't enough", and the competition was waiting for George Washington to blow up. They never did, but because of their desire to stay in the race for first, George Washington overextended their battery resources on days 3 and 4 and suffered the consequences on day five. A more conservative strategy would have paid dividends, but then again, almost everyone gambled on the weather and lost.

With rock solid reliability, Stanford moved steadily along and bested many potentially faster cars. After their disastrous fire, their preparation and race execution was nearly flawless. Maryland also had a very reliable car, and except for a rear trailing arm that sheared, they had no significant failures. Maryland came very close to their potential speed, as did Stanford. Incidentally, both Maryland and Stanford were unable to qualify at a regional qualifier and had to qualify at Arlington.

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1. Kyle, C.R., ***Racing with the Sun***. The 1990 World Solar Challenge. *Society of Automotive Engineers, Warrendale PA. 1991.*

2. Coutts, T., L. Kazmerski & S. Wagner. ***Solar Cells***, *31:5: Nov. 1991.*

Appendix 1

Solar Radiation, Sunrayce 93

(Watts per square meter)

Day 1

Arlington, TX Start		Whitesberro, TX 124.9 km (77.6 mi)		Ada, OK 261.6 km (162.6 mi) Finish	
8AM	48.7	10AM	190.4	12 PM	624.7
9AM	134.5	11AM	173.9	1PM	449.7
10AM	136.1	12AM	285.7	2PM	570.5
11AM	200.5	1PM	317.0	3PM	911.3
		2PM	375.2	4PM	783.5
		3PM	498.5	5PM	480.8
				6PM	587.2
				7PM	398.6
				8PM	154.2

Day 2

Ada, OK Start		Shawnee, OK 78.8 km (49.0 mi)		Tulsa, OK 272.4 km (169.3 mi) Finish	
7AM	4.2	9AM	283.8	2 PM	606.2
8AM	36.5	10AM	304.9	3PM	845.2
9AM	135.6	11AM	401.4	4PM	682.6
10AM	195.7	12PM	390.9	5PM	508.9
11AM	1.1	1PM	764.0	6PM	312.9
12PM	1.5	2PM	655.9	7PM	208.8
1PM	11.6			8PM	141.8

Day 3

Tulsa, OK Start		Miami, MO 152.9 km (95.0 mi)		Fort Scott, KS 312.8 km (194.4 mi) Finish	
7AM	35.3	9AM	438.8	11AM	821.2
8AM	144.4	10AM	614.5	12PM	822.9
9AM	352.3	11AM	649.3	1PM	996.8
10AM	478.3	12PM	701.2	2PM	907.1
11AM	659.8	1PM	780.1	3PM	741.9
12PM	411.2	2PM	756.2	4PM	650.7
1PM	742.1	3PM	961.0	5PM	761.8
2PM	743.2	4PM	778.4	6PM	547.3
		5PM	687.4	7PM	222.6
				8PM	92.5

Day 4

Fort Scott, KS Start		Kansas City, MO 145.1 km (90.2 mi)		Cameron, MO 262.7 km (163.3 mi) Finish	
6AM	0.9	9AM	315.7	10AM	680.2
7AM	44.2	10AM	290.4	11AM	706.4
8AM	194.2	11AM	578.9	12PM	606.1
9AM	394.6	12PM	573.2	1PM	406.8
10AM	583.9	1PM	138.9	2PM	319.5
11AM	711.0	2PM	57.1	3PM	164.0
12PM	728.4			4PM	283.2
1PM	650.3			5PM	303.6
2PM	262.4			6PM	244.8
3PM	12.4			7PM	169.7
4PM	8.0			8PM	91.2
5PM	30.6			9PM	20.5
6PM	43.3				
7PM	31.9				
8PM	41.1				
9PM	13.0				

Day 5

Cameron, MO Start		Lineville, IA 133.7 km (83.1 mi)		Des Moines, IA 259.0 km (161.0 mi) Finish	
7AM	32.0	10AM	61.2	12PM	504.6
8AM	108.4	11AM	299.4	1PM	350.3
9AM	32.2	12PM	254.4	2PM	57.9
10AM	66.9	1PM	174.1	3PM	81.4
11AM	193.4	2PM	107.2	4PM	131.8
12PM	388.9	3PM	140.1	5PM	214.0
				6PM	378.0
				7PM	366.7
				8PM	176.4

(Watts per square meter)

DAY 6						DAY 7	
Des Moines, IA Start		Iowa Falls, IA 140.8 km (87.5 mi)		Albert Lea, MN 274.2 km (170.4 mi) Finish		Albert Lea, MN (Start) Finish in Minneapolis @ 142.7 km (88.7 mi)	
6AM	3.3	10AM	647.6	1 PM	962.7	6AM	15.1
7AM	20.4	11AM	788.2	2PM	876.7	7AM	97.0
8AM	197.1	11AM	907.5	3PM	654.7	8AM	263.7
9AM	433.5	12PM	976.4	4PM	639.0	9AM	452.4
10AM	624.2	1PM	990.7	5PM	587.8	10AM	625.9
11AM	781.6	2PM	941.5	6PM	452.1	11AM	769.5
		3PM	718.2	7PM	337.5	12PM	886.0
				8PM	124.6		

Note: The solar radiation given in these tables is the integrated average for 1 hour (prior to the given time) in watts/m². For example 8 AM = 48.7 is 48.7 watts/m² average for the hour from 7:00AM to 7:59 AM. The data were gathered along the Sunrayce route by Jeff Alleman and Craig Marshall of the National Renewable Energy Laboratory.

Appendix 2

Difficulties and Problems Before and During Sunrayce 93

The following list illustrates the unplanned troubles that can plague a solar car before and after completion. This list, compiled by the Stanford Team, is included because it may help others avoid similar problems.

Problems Experienced by the Stanford Team

1. Lack of a proper battery box and insulation allowed the Pulsar batteries to bounce and short out while the car was being trailered to a test site. Combustible blue Styrofoam was ignited by the heat. Fire wasn't noticed until van driver saw smoke pouring out of trailer. The car was almost a total loss: 4m^2 (43.2 ft^2) of cells destroyed, 8 m^2 (86.4 ft^2) of array structure destroyed, over half of aerodynamic fairing destroyed, but main chassis, mechanical and electrical systems are not severely damaged. Car repaired in the two months left before the race.
2. Rear tire blowout during testing causes driver to lose control of car at 32.2 kph (20 mph). The same instability occurred with 2 flats during the race.
3. Seals in brakes' master cylinder fail, brakes lose pressure.
4. Brake pedal designed poorly without adequate mechanical advantage: Line pressure deficient, sloppy braking. Thin, aluminum Mountain cycle brand brake discs easily warp, causing brake drag.
5. Car too hot: 54°C (130°F) inside driver's bubble on a 38°C (101°F) day.
6. Due to flexure of chassis, array attachment pins sometimes don't line up with their holes.
7. Solar car collides with rear end of lead vehicle at 24 kph (15 mph). Damage to steering column, brake pedal, array structure. Even though the solar car met Sunrayce braking specs, braking was inadequate in everyday traffic.
8. Set screws in steering rods came loose. Steering inoperable.
9. Motor mounting plate accidentally machined out of weak cast aluminum alloy, it was replaced with stronger material.
10. Our use of tires with Mr. Tuffy insert nearly doubled the car's rolling resistance.
11. Wheel nuts fell off as installed, without nylon lock nuts, retaining pins, or Loctite.
12. Bolts on rear drive cog, without Loctite, came loose and scraped the suspension swing arm, shaving an aluminum part and bringing the car to a stop.
14. Rear spindle threads failed due to over-tightening of wheel nut, wheel dropped off in tightener's hands.
15. Front wheel rim catastrophically failed, at 32 kph (20 mph). No damage to the chassis because the car slid on the brake disc.
16. Metal weld spatter on rim of wheel leads to blowouts since tire bead can't seat itself.
17. Tires loaded too high, leading to sidewall failure and blowouts.
18. Design mistake in front hubs. Spoke holes not offset from those on opposite flange. Building front wheels was not impossible, but very difficult.
19. Short circuits between cells and the carbon fiber array structure, four small fires started.
21. Steering arm rod end is bent while driving due to improper installation.
22. Car not waterproof. Water in car.
23. Cog put on motor shaft backwards, eats hole in motor mount plate. Cog comes off of motor shaft.
23. Wheel caught in trolley track, rim bent.
24. Loss of power shunt that was rated too low (5 amp shunt used in 20-30 amp situation).
25. Wheel covers fall off.
26. Steering system snaprings catch and cause steering lockup, loose steering wheel due to U-joint being .012 cm (.005 inch) smaller than ID of bearing causes considerable backlash in steering.
27. Some purchased parts had less than advertised performance. Solar cells represented as 17% efficiency were actually 15%.

Problems Reported by Other Teams and Compiled by Stanford

1. Chase vehicle ran into solar car making a quick stop at a traffic signal. This is an avoidable accident as was Stanford's collision above. Tailgating by race vehicles is dangerous and should be avoided.
2. Controller/motor burn out, twice on same car. Probably due to a wiring error in the electronics.
3. Fragile solar arrays were damaged from accidents such as dropped loaded tool chest and items falling from cupboards during trailering.
4. Wheels represented as graphite were in reality weak injection-molded plastic and collapsed during qualification.
5. A good rule of thumb is that if a car works during practice,

then untested things shouldn't be changed for the race. One team put an anti-corrosion gel on the battery contacts. The gel is supposed to be added only after the wiring is fastened and complete, but they applied the gel to the parts before connecting them. The contacts melted.

6. Two teams forgot to plug in all or part of the solar array before the start. Faulty array connectors, that were undetected, had the same effect, depleated batteries on the first day.
7. Brake drag due to a brake pad rubbing against the disc was a common problem, causing speed loss and battery drain.
8. Many cars suffered broken spokes due to crosswinds.
9. A narrow wheel got caught between parallel sewer gratings, bent the wheel and broke a carbon fiber steering arm as they tried to steer out of the grate.
10. Many cars poorly understood their battery capacity, discharging the batteries to the point where they could not recover under the poor sun conditions.
11. Front suspension bolt and steering knuckle failed.
12. Hit a large road reflector at race speed bouncing one side of the car into the air, bending shock-push-rod, and fracturing lower strut's welded joint. Rear swing arm cracks and failures were common.
14. The tactic of deliberately missing the starting deadline to gain extra battery charge was rarely a good trade off due to substantial time penalties.
15. Risse Racing Technology mountain bike shocks were sold with inadequate air pressure valves, leading to depressurization of the shocks. Risse serviced the teams during the race, replacing the needle valves with standard Shrader valves.
16. Aerodynamic fairings, which should have improved aero performance by covering vehicle wheels, instead cut into the tires and had to be removed before the race began. Pre-race practice could avoid this.
18. A whole array structure began to sag and melt in the summer heat, because the curing resin used in construction was only rated to 65° C (150° F).
19. Bypass diodes were installed backwards, but were fixed before the race.
20. One team mixed 6V and 12V batteries, which on paper had the same specifications and should have performed identically. The 6V batteries, however, were from a different batch and were not matched well enough to the 12V batteries. The 6V batteries soon died, and the team had to take a time penalty to switch to a new battery pack during the race.
21. An Amp-hour meter shunt was scratched during installation. Although scratching a resistor seems harmless, one team found that damage to that very low and precise resistor caused readings on their amp-hour meter to be off by a factor of two during the race.

Appendix 3

Vehicle Technical Data

1st Place

Car: #1 University of Michigan. "Maize & Blue". 1301 Beal St., Ann Arbor MI (313) 936-1441, FAX (313) 763-9487
Time: 40.66 hrs
Average Speed: 43.90 kph (27.29 mph)
Penalties: 0.5 hrs
Speed w/o Penalties: 44.46 kph (27.63 mph)
Days Finished Before 6:30 p.m.: 7
Total Distance: 1785.2 km (1109.5 mi) (Finished all days)
Country: USA

Team Captain: Furqan Nazeeri
Faculty Advisors: Dr. Bruce Karnopp, Dr. Gene Smith
Team Members: Joseph Bartlo, Leslie Camblin, Andrew Carmody, William Cosnowski, Kristine Gearhart, Kevin Cain, Ignacio Garcia, Mark Kulie, Stephen Lukachko, Charles Mentzer, Ketan Patel, Birger de la Peña, Jeff Reese, Daniel Ross, Andris Sampsons, Eric Slimko, Brian Theis, J. Andrew Walberer, Andrew Warner, Elizabeth White, Deanna Winton, Harry Yates, Jeff Zoltowski, Steve Wickham
Cost: $575,000
Project Time: 2 1/2 years

Drag Coefficient, Cd: 0.115
Frontal Area A: 1.16 m² (12.53 ft²)
Drag Area CdA: 0.133 m² (1.44 ft²). Measured full scale in the Lockheed, Atlanta, Georgia, 4.9 x 6.1 meter (16 x 20 foot) wind tunnel with boundary layer blowing to simulate moving ground plane.

Qualifying Speed: 64.0 kph (39.8 mph), 10th
Average Race Speed: 43.93 kph (27.3 mph)
Best Daily Average Speed: 1.5 kph (32.0 mph)
Slowest Daily Average Speed: 28.0 kph (17.4 mph)
Daily Average Speed kph (mph)

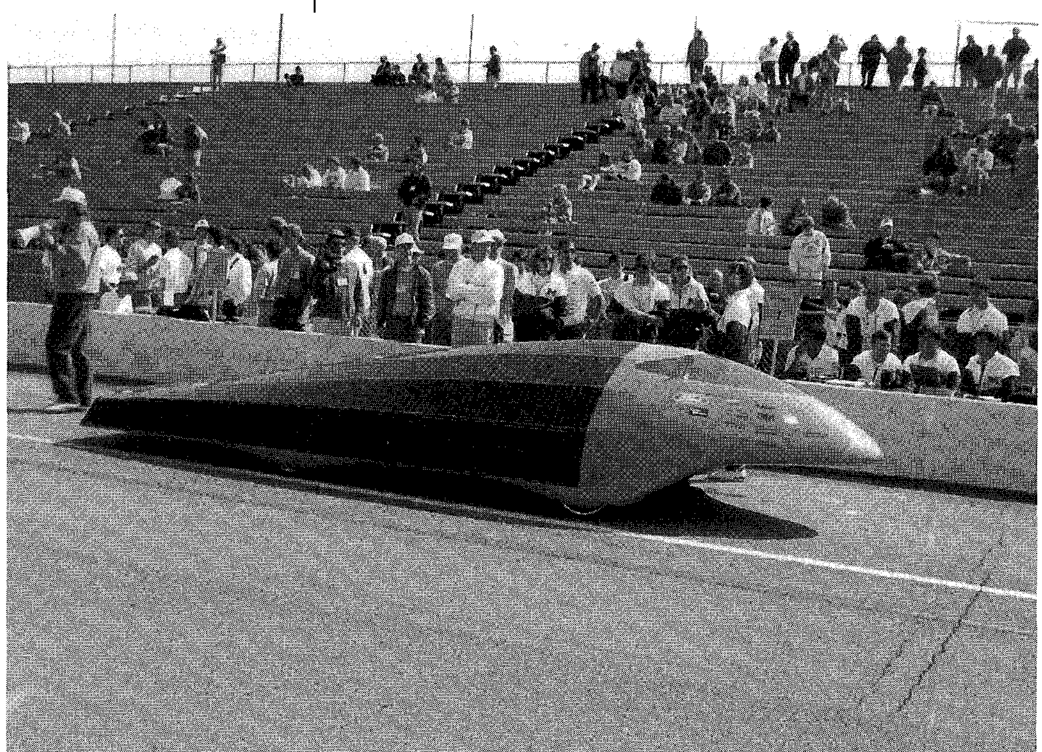
1	48.38	(30.07)*
2	50.81	(31.58)
3	51.52	(32.02)
4	48.91	(30.40)
5	27.96	(17.38)*
6	43.35	(26.94)
7	50.70	(31.51)

*Top speed for the day.

Weight w/o Driver: 358 kg (790 lb)
Length: 5.75 m (18.87 ft)
Width: 2 m (6.56 ft)
Height: 1.1 m (3.61 ft)
Wheelbase: 2.2 m (7.22 ft)
Track Width: 1.89 m (6.20 ft)
Clearance: 0.45 m (1.48 ft)

Wheels and Tires: 36 spoke, 43.18 cm (17 inch) wheels with spoke covers; Michelin/Moulton 43.18 x 3.18 cm (17 x 1.25 in) slick tires @ 120 psi
Number of Wheels: 4
Est. Tire Rolling Resistance Coefficient: 0.0060
Number of Flat Tires During the Race: 3

Brakes, Suspension, and Steering: Hydraulic motorcycle disk front brakes. No emergency brake (used chocks) Regenerative braking. Custom titanium suspension parts. Modified MacPherson strut with Monroe custom shocks in front, 86 lb/in separate coil spring. Trailing arm rear, with 236 lb/in coil over shocks. Rack and Pinion steering with two redundant push-pull cables.



1st Place - University of Michigan

Chassis: 6061-T6 Aluminum tubing space frame, 2.54 cm (1 in) OD, .11 cm (.045 in) wall. Carbon/Nomex body, Kapton insulators between panel and body.
Motor: Custom MagnaTek DC brushless, 1.8 kW rated, 3.7 kW max, 2250 RPM, 100 volts, 14.5 kg (32 lb), 93% efficient at operating power level, 95% peak efficiency. Blower cooling.
Controls and Instrumentation: Constant power/constant speed motor controller. Telemetry of voltages, currents, temperatures, speed to chase van.
Transmission: Direct drive chain to rear wheel, 2.06/1 ratio typical.

Batteries: Eagle Picher, 3 parallel packs, 96 volts, 4.8 kWh, 54 ah, 154 kg (340 lb)
Battery Charge Each Day, Percent at Start/Finish:
1 100%/20%
2 80/20%
3 70/30%
4 100/15%.
5 36/-5%
6 30/30%
7 80/60%
Solar Cells: BP Solar Saturn Cells, Laser Grooved, Monocrystalline Silicon, 7615 cells, 90% areal packing, 17% single cell rated efficiency, 16.3% mean single cell observed efficiency measured at TRW in Redondo Beach, CA. Average was for 8000 cells processed. Overall panel efficiency 14.5%, 1300 watts peak. 8 facets of 3 modules each. 8 AERL peak power trackers.

Type of Solar Panel: Fixed panel with a eight gently curved facets.
Panel Voltage: 130 volts
Reported Maximum Instantaneous Panel Power During Race: 1300 W
Reported Panel Power on a Sunny Day at High Noon: 1000 W
Reported Average Panel Power From 8 a.m. to 5 p.m. During a Sunny Day: 800 W

Reported Speed on 1000 Watts of Panel Power: 69 kph (43 mph)

Notes and Reported Problems During the Race: Replaced 3 damaged solar cells on day 6, 1/2 hour. Shunt for ampere-hour counter failed (mfg. Brusa). Michigan practiced 4827 kilometers (3000 miles), 804.5 kilometers (500 miles) of the actual race course. Conducted 2 surveys of the race route. In practice, near Tulsa, bent a wheel rim on a storm grating, which was avoided during the race. The weather team from Atmospheric & Ocean Sciences of Michigan helped by providing updated satellite color weather plots as well as computerized weather files to the chase van during the race. Knowing the weather ahead along the route allowed Michigan to manage battery resources efficiently. In pre-race testing, power consumption was excessive and a systematic check of all systems showed the brakes were rubbing, and retractable pads were designed which saved 200 watts. Bearings with steel seals were installed with chrome-moly lube to minimize bearing friction. Coast down tests determined rolling losses were normal. Also experienced significant instrumentation errors during pre-race testing. During the race, Michigan's car ran reliably.

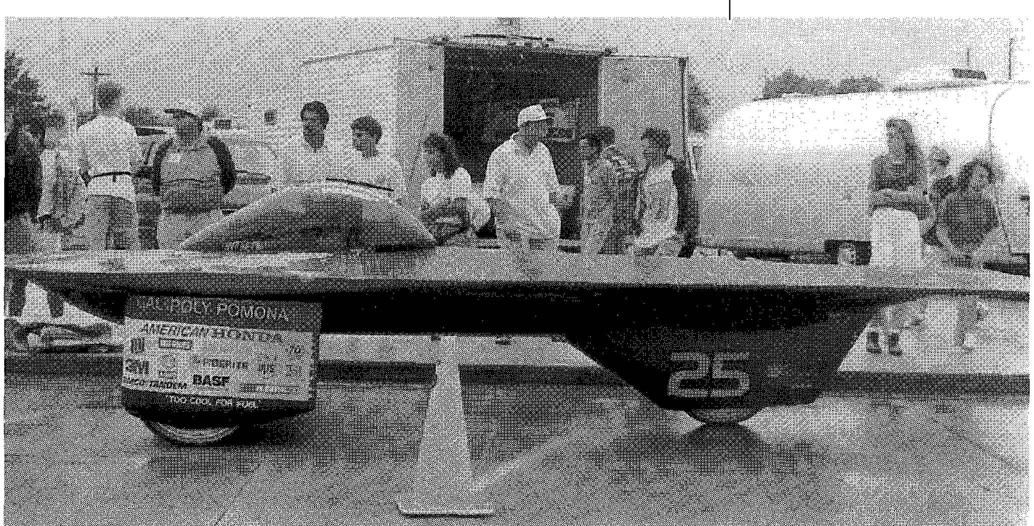
2nd Place

Car: #25 California State Polytechnic University, Pomona. "Intrepid". CaPSET Project 3801 W. Temple Avenue, Pomona, CA 91768-4066 (909) 869-4367, FAX (909) 869-4370
Time: 42.16 hrs
Average Speed: 42.35 kph (26.32 mph)
Penalties: 1.733 hrs
Speed w/o Penalties: 43.14 kph (26.80. mph)
Days Finished Before 6:30 p.m.: 6
Total Distance: 1743.4 (1083.5 mi)
Country: USA

Team Captains: Alan Redmond, Wayne Watson, Tina Shelton
Faculty Advisors: Dr. Michael T. Shelton, Don G. VandeGriff, Gerald Herder, Dr. Elhami Ibrahim
Team Members: Grant Ager, Mike Anderson, Craig Baxter, David Chen, Jacob Christ, Kelvin Kido, Jim Miller, Mike Monte, Filiberto Moreno, Keith Murray, Charles Suh, Bill Watson, Marilyn Watson, Peter Boor
Cost: $150,000
Project Time: 1 1/2 years

Drag Coefficient, Cd: 0.17
Frontal Area A: 1.1 m^2 (11.88 ft^2)
Drag Area CdA: 0.19 m^2 (2.05 ft^2)
1/6 scale model wind tunnel test.

Qualifying Speed: 73.7 kph (45.8 mph), 5th
Average Race Speed: 42.3 kph (26.3 mph)



2nd Place - California State Polytechnic University, Pomona

Best Daily Average Speed: 54.4 kph (33.8 mph)
Slowest Daily Average Speed: 23.2 kph (14.4 mph)
Daily Average Speed kph (mph):

1	47.43	(29.48)
2	51.70	(32.13)*
3	54.40	(33.81)*
4	47.72	(29.66)
5	23.17	(14.40)
6	45.28	(28.14)
7	50.30	(31.26)

*Top speed for the day.

Weight w/o Driver: 303.5 kg (669 lb)
Length: 6.0 m (19.7 ft)
Width: 2 m (6.6 ft) **Height:** 1.3 m (4.27 ft)
Wheelbase: 2.37 m (7.78 ft)
Track Width: 1.76 m (5.77 ft)
Clearance: 0.38 m (1.25 ft)

Wheels and Tires: 48 spoke, 66 cm (26 in) wheels with spoke covers; Tioga 5 x 66 cm (1.95 x 26 in) City Slickers @ 90 psi
Number of Wheels: 3
Est. Tire Rolling Resistance Coefficient: 0.0078
Number of Flat Tires During the Race: 0

Brakes, Suspension, and Steering: Front and rear hydraulic go-cart disc brakes with positive spring return pads. Front Honda modified motorcycle forks with rack and pinion steering, rear trailing arm with coil over shock.
Chassis: Carbon/Nomex/Beam-Monocoque frame. Kevlar/Nomex face sheets-body.
Motor: Hathaway DC brushless, 1.3 kW rated, 2.3 kW max, 5000 RPM, 96 volts, 23 amps, 6.4 kg (14.1 lb), 90% efficient at operating power level. Polar Power controller. Blower cooling.
Controls and Instrumentation: Constant speed or constant current motor controller. Telemetry of array zone current, buss voltage, battery current, motor RPM/temperature and controller temperature to lead van.
Transmission: Direct drive chain to rear wheel, 12/1, 8/1 ratios, typical, #41 chain.

Batteries: Sears/Johnson Controls, 8 batteries parallel packs, 96 volts, 5 kWh, 51.9 ah, 118 kg (260 lb).
Battery Charge Each Day, Percent at Start/Finish

1	100%/20%
2	95/5%
3	93/14%
4	97/2%.
5	33/0%
6	65/25%
7	100/60%

Solar Cells: BP Solar, Monocrystalline Silicon, 1092 cells, 17% single cell rated efficiency, actual efficiency 15.5%, 1100 watts peak. 80 strings of 14 in 3 zones. Actual active coverage, 7.59 m^2 (82 ft^2) out of 8 m^2 (86.4 ft^2)=95%. 4 AERL peak power trackers. One bottom panel spread out during the evening and morning charging periods for more area.

Type of Solar Panel: Fixed panel with a two gently warped facets.

Panel Voltage: 150 volts
Reported Maximum Instantaneous Panel Power During Race: 1292 W
Reported Panel Power on a Sunny Day at High Noon: 1034 W
Reported Average Panel Power from 8AM to 5PM During a Sunny Day: 733 W
Reported Speed on 1000 Watts of Panel Power: 57.92 kph (36 mph)

Notes and Reported Problems During the Race: Interconnect on solar array broken, soldered. Chain popped off drive sprocket when set screw backed off. Stalled several times on hill with low battery, had to go to bottom of hill and take a run at it. Had three broken solar cells and the Tefzel delaminated in spots. Occasionally lost telemetry. As improvements, plan to clean up wheel fairings to avoid aero interference with the body. Need to have faster sprocket change means and closer gear ratios. Practiced 1931 kilometers (1200 miles) before race. A check of performance data revealed a 200 watt loss at low speed, cause unknown although the wheel bearings may have been deformed or there is an undetected problem in the drive system.

3rd Place

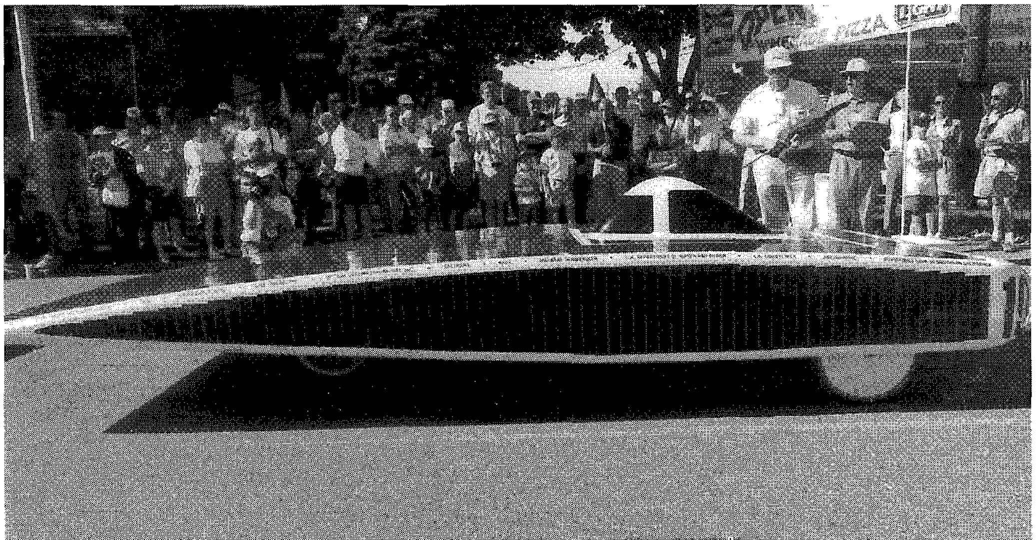
Car: #19 California State University, Los Angeles. "Solar Eagle II". School of Engineering & Technology, Los Angeles, CA 90032 (213) 343-4477, FAX (213) 343-4555
Time: 45.45 hrs
Average Speed: 39.28 kph (24.41 mph)
Penalties: 2.413 hrs.
Speed w/o Penalties: 40.26 kph (25.02 mph)
Days Finished Before 6:30 p.m.: 6
Total Distance: 1739.00 km (1080.8 mi)
Country: USA

Team Captain: Ricardo Espinosa.
Faculty Advisor: Richard Roberto
Team Members: Erick Juarez, Tai Nuyen.
Cost: $160,000
Project Time: 17 months

Drag Coefficient, Cd: 0.140
Frontal Area A: .96 m^2 (10.37 ft^2)
Drag Area CdA: 0.134 m^2 (1.45 ft^2). 1/6th full scale wind tunnel model and coast down test on hill.

Qualifying Speed: 80.5 kph (50.0 mph), 1st
Average Race Speed: 39.3 kph (24.4 mph)
Best Daily Average Speed: 69.6 kph (43.23 mph)
Slowest Daily Average Speed: 22.04 kph (13.7 mph)
Daily Average Speed kph (mph)

1	30.49	(18.95)
2	42.56	(26.45)
3	48.46	(30.12)
4	52.05	(32.35)*
5	22.06	(13.71)
6	53.76	(33.41)*



3rd Place - California State University, Los Angeles

7 69.62 (43.27)*
*Top speed for the day.

Weight w/o Driver: 287 kg (633 lb)
Length: 4.9 m (16.1 ft)
Width: 1.842 m (6.04 ft)
Height: 1 m (3.28 ft)
Wheelbase: 2.44 m (8 ft)
Track Width: 1.47 m (4.82 ft)
Clearance: 0.31 m (1.02 ft)

Wheels and Tires: 36 spoke, 51 cm (20 in) wheels with spoke covers; Avocet 51 x 4.4 cm (20 x 1.75 in) slick tires @ 90 psi
Number of Wheels: 3
Est. Tire Rolling Resistance Coefficient: 0.0055
Number of Flat Tires During the Race: 2

Brakes, Suspension, and Steering: Hydraulic disk brakes, with friction tire emergency brake. Regenerative Braking. Double A arm in front, rear trailing arm, with Works performance custom coil over shocks. Rack and pinion steering, half turn lock to lock.
Chassis: Hybrid frame. Aluminum tubing with carbon composite shear panels. Body constructed of carbon, T400/Granack/Rohla cell structural foam sandwich.
Motor: Solectria BRLS8, DC brushless, 5.7 kW rated, 6000 RPM, 170 volts, 11.8 kg (26.02 lb), 90% efficient at operating power level, 93% peak efficiency. Blower cooling. Solectria motor controller.
Controls and Instrumentation: Constant speed motor control. Cab display of operating functions. Telemetry to chase vehicle.
Transmission: Direct drive gates cog belt to rear wheel, 4 3/4, 5 1/4, 6/1 ratios available.

Batteries: US Battery. 12 batteries, 144 volts, 4.95 kWh, 34 ah @ 20 hour discharge, 27 ah @ four hour discharge rate. 109 kg (240 lb).
Battery Charge Each Day, Percent at Start/Finish
1 100%/10%
2 50/5%
3 65/10%
4 80/2%
5 22/0%
6 50/-0%
7 82/20%
Solar Cells: BP Solar, Monocrystalline Silicon, 1570 cells (824 on sides), 16% single cell rated efficiency, 1050 watts peak. 4 strings, 2 top and 2 sides. 4 AERL peak power trackers (new racing trackers), one pound weight each, 98% efficient. Bora silicate laminated cover glass over solar cells with anti-reflecting coating. Keeps cells cooler and improves radiation absorption.

Type of Solar Panel: Fixed top solar panel with two side panels
Panel Voltage: 220 to 250 volts input to power trackers.
Reported Maximum Instantaneous Panel Power During Race: 1400 W
Reported Panel Power on a Sunny Day at High Noon: 1050 W
Reported Average Panel Power from 8am to 5pm During a Sunny Day: 800 W
Reported Speed on 1000 Watts of Panel Power: 61 kph (38 mph)

Notes and Reported Problems During the Race: Controller failed four times. Changed controller twice. Changed motor three times. The controller had 1931 kilometers (1200 miles) on it before the race (practice). Had short in panel first day, causing a loss of 200 watts in power. Something caused the motor to switch unexpectedly to reverse on the road the first and second day. Lost three hours the first day and five hours the second day. Replaced controller switch.

4th Place

Car: #7—The George Washington University. "Sunforce I". 801 22nd St. NW, Wash., DC 20052 (202) 994-6915, FAX (202) 994-0238
TIme: 46.12 hrs **Avg. Speed**: 38.71 kph (24.06 mph) **Penalties**: 5.76 hrs **Speed w/o Penalties**: 41.14 kph (25.57 mph) **Days Finished Before 6:30 p.m.**: 6
Total Distance: 1661 km (1032.1 mi)
Country: USA

Team Captain: Barrett Crane
Faculty Advisors: Dr. Nabih Bedewi, Joel Jermakian
Team Members: Rob Piacesi, Stephane Thiriez, Ben Feldman, Jay Newlin, Cory Knudtson, Kevin Groot, Eric Takamura, Nicole Michels, Jason FB Ennis, Steve Crain, Charlie Mercier, Mike Kuberski, Mark Matsumura, Italo Travez, Desle Francis, Bud Zaouk, Siew Ng, Luis Valle, Jay Hudnall

Cost: $120,000
Project Time: 1 1/2 years

Drag Coefficient, Cd: 0.16
Frontal Area A: 0.6 m² (6.5 ft²)
Drag Area CdA: 0.10 m² (1.1 ft²) 3/8 scale wind tunnel model.

Qualifying Speed: 41.4 kph (25.7 mph), 15th
Avg. Race Speed: 38.8 kph (24.1 mph)
Best Daily Avg. Speed: 64.8 kph (40.3 mph)
Slowest Daily Avg. Speed: 17.4 kph (10.8 mph)
Daily Average Speed kph(mph)
1 47.1(29.27)
2 45.55(28.31)
3 50.91(31.64)
4 50.17(31.18)
5 17.39(10.81)
6 45.2(28.09)
7 64.91(40.34)

Weight w/o Driver: 291 kg (641 lb)
Length: 6 m (19.7 ft)
Width: 1.84 m (6.04 ft)
Height: 1 m (3.28 ft)
Wheelbase: 2 m (6.6 ft)
Track Width: 1.1 m (3.61)
Clearance: 0.2m (.66 ft)

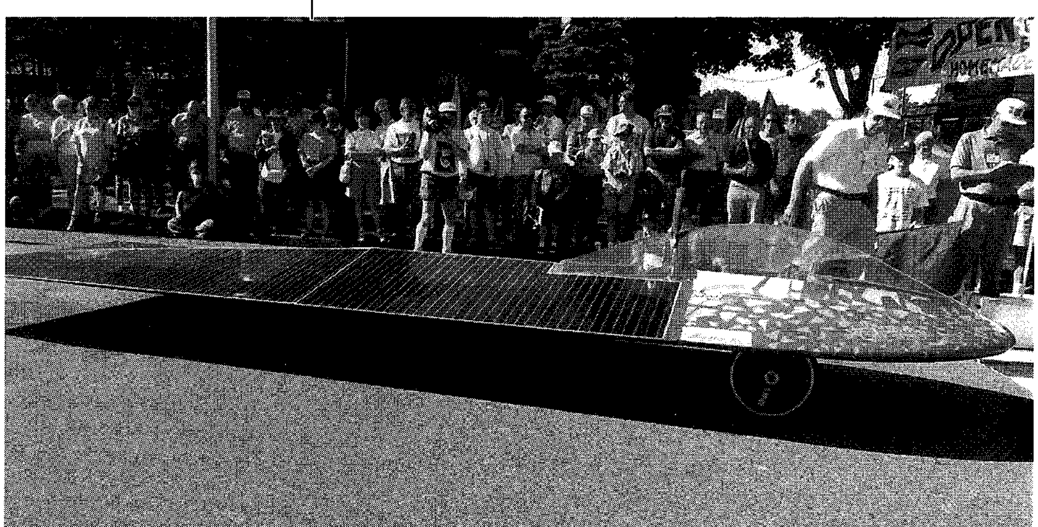
Wheels and Tires: 28 spoke, 43.2 cm (17 in) wheels with spoke covers; Moulton 43.2 x 3.2 cm (17 x 1.25 in) slicks @ 140 psi
Number of Wheels: 4 (2 in front, 2 narrowly spaced in rear)
Est. Tire Rolling Resistance Coefficient: 0.0060
Number of Flat Tires During the Race: 21

Brakes, Suspension, and Steering: Hydraulic disk front brakes, regenerative rear brakes. Double A arm front with coil over nitrogen charged shocks, rear trailing arm with coil over shocks. Rack and Pinion steering.
Chassis: Modified monocoque frame with carbon/foam/honeycomb construction. Kevlar/honeycomb sandwich array. Foam gives strength in compression, honeycomb does not—foam sandwich is used at points of compression. Two main carbon/foam spars with cross bulkheads to support the suspension.
Motor: Solectria DC brushless, 6 kW rated, 12 kW max, 6000 RPM, 96 volts, 11.8 kg (26 lb), 89% operating eff. Muffin fan cooling.
Controls and Instrumentation: On board computer to monitor system information in real time.
Transmission: Double reduction gates cog belt drive.

Batteries: Optima, 7 batteries, 84 volts, 4.7 kWh, 56 ah, 127 kg (280 lb). Ampere-hour computer.
Battery Carge Each Day, Percent at Start/Finish
1 100%/20%
2 75/10%
3 80/0%
4 50/5%.
5 25/5%
6 25/5%
7 95/40%
Solar Cells: BP Solar Cells, Laser Grooved, Monocrystalline Silicon, 1778 cells (504 on bottom sides of car), 17% single cell rated efficiency, 15 1/2% actual, 14% panel efficiency in operation. 1000 watts peak, 64% fill factor. Five strings. 6 AERL peak power trackers. The bottom panels spread out during the evening and morning charging periods for more area. Panel is removeable

Type of Solar Panel: Fixed panel with two gently warped facets.
Panel Voltage: 120 volts
Reported Maximum Instantaneous Panel Power During Race: 1000 W
Reported Panel Power on a Sunny Day at High Noon: 1000 W
Reported Average Panel Power From 8 a.m. to 5 p.m. During a Sunny Day: 650 W
Reported Speed on 1000 watts of Panel Power: 64.4 kph (40 mph)

Notes and Reported Problems During the Race: Grounded bus to chassis, burned cable. Solar panel connections difficult to repair, high resistance at contacts, which lower the output of the array. In first place on day 2 until one mile from finish the left wheel fell into a rain grate, breaking the carbon knuckle arm and destroying a wheel, lost 45 minutes. After the finish, the carbon knuckle arms were replaced with aluminum. This mishap could have been avoided with better driver visibility. The canopy was fixed for the next day of racing. Front dampers



4th Place - George Washington University

5th Place - Stanford University

did not allow ride height to be accurately set. On day 6, the right brake was not set properly and dragged all day, lost approx. 8 kph (5 mph) off average speed from power consumption data. Had excessive number of flats because of inaccurate pressure gauge. Lost about 1 hour in tire changes. Took about a minute to change front wheels and less than 3 minutes to change rear wheel.). Motor speed hard to control. Some failures in electronic components during race, these were replaced rapidly. Not enough testtime on vehicle prior to race, 113 kilometers (70 miles) is not enough. It is hard to balance the load between the two narrowly spaced rear wheels, had to stiffen the rear trailing arm to prevent excessive tire wear on one rear tire. At the qualifier, there was excessive power consumption due to wheel misalignment. It was measurably better after alignment.

5th Place

Car: #101 - Stanford University. "Sunburner". P.O. Box 8827 Stanford, CA 94309 (415) 473-0471, FAX (415) 723-0010
Time: 3.047 hrs
Avg. Speed: 33.81 kph (21.01 mph)
Penalties: 3.07 hrs.
Days Finished Before 6:30 p.m.: 6
Total Distance: 1712 km (1063.8 mi)
Country: USA

Team Captain: Alex Tilson.
Faculty Advisor: Alex Garoutte
Team Members: Chris Shaw, Jason Garoutte, Joe Seeger, Johnny Chen, Nathan Rutman, Ken Johnson, Charles Nickel, Kate Von Reis, Brett Bowman, Mark Schieff, Dorian West, Tom Hsiu, Chris Rowe, Scott Snyder, Vik Gupta.
Cost: $120,000
Project Time: 2 1/2 years.

Drag Coefficient, Cd: —
Frontal Area A: .— m^2
Drag Area CdA: 0.204 m^2 (2.20 ft^2). Lockheed Wind Tunnel full scale measured CdA.
Qualifying Speed: 37.0 kph (23.0 mph), 32nd
Avg. Race Speed: 33.8 kph (21.0 mph)
Best Daily Avg. Speed: 46.7 kph (29.0 mph)
Slowest Daily Avg. Speed: 20.8 kph (12.9 mph)
Daily Average Speed kph(mph)
1 38.86 (24.15)
2 37.76(23.47)
3 43.12(26.80)
4 31.27(19.44)
5 20.76(12.90)
6 35.98(22.36)
7 46.6(28.96)

Weight w/o Driver: 349.3 kg (770 lbs)
Length: 6 m (19.7 ft)
Width: 2 m (6.6 ft)
Height: 1.1 m (3.6 ft)
Wheelbase: 3 m (9.8)
Track Width: 1.1 m (3.6 ft)
Clearance: 0.17 m (.056 ft)

Wheels and Tires: 48 spoke, 51 cm (20 in) wheels with spoke covers; Avocet 51 x 4.4 cm (20 x 1.75 in) slick tires @ 100 psi
Number of Wheels: 3
Est. Tire Rolling Resistance Coefficient: 0.0055
Number of Flat Tires During the Race: 3

Brakes, Suspension, and Steering: Front Airhart master cylinder, pro Stop disc, Enginetics carbon fiber calipers. Rear regenerative brakes and bike caliper emergency brake. Front double A arm. Oil/air damper mountain bike shocks. Carbon fiber rear trailing arm with Reese racing mountain bike shocks. Rack and Pinion steering.
Chassis: Plank chassis with 5 cm (2 in) thick backbone. Carbon/ Nomex honeycomb. Room temperature lay up.
Motor: Solectria DC brushless, 6 kW rated, 12 kW max, 4000 RPM, 120 volts, 13 kg (29 lb), 92% efficiency operating, 94% peak efficiency.
Controls and Instrumentation: Constant current cruise control. Continuous 3 channel micro processor, displays volts/ current /amp hours for array, motor, and battery.
Transmission: Direct single reduction drive Gates cog belt. 98% efficient. Motor mounted on composite swing arm. Aluminum 148 and 160 tooth cogs, CNC hollowed, then core and face sheets bonded on.

Batteries: 10 Gates batteries, 120 volts, 4.5 kWh, 38 ah, 150 kg (330 lb).

Battery Charge Each Day, Percent at Start/Finish
1 100%/30%
2 45/25%
3 40/15%
4 35/-10%.
5 5/-10%
6 15/-5%
7 50/45%

Solar Cells: BP Solar Cells, Laser Grooved, Monocrystalline Silicon, 798 cells, 92% areal packing, 17 1/2% single cell rated efficiency 15 1/2% actual, 1150 watts peak. 4 Brusa peak power trackers.

Type of Solar Panel: Fixed panel with a 2D flat wave shape.
Panel Voltage: 100 volts
Reported Maximum Instantaneous Panel Power During Race: 1150 W
Reported Panel Power on a Sunny Day at High Noon: 900 W
Reported Average Panel Power From 8 a.m. to 5 p.m. During a Sunny Day: 700 W
Reported Speed on 1000 Watts of Panel Power: 56 kph (35 mph)

Notes and Reported Problems During the Race: Project and construction entirely student run. Cross winds created huge side thrust and caused instability, but also decreased drag. Solar panel carbon substrate electrical ground fault before race, had to isolate panel. Cruise control failed during race. Couldn't get hub off after flat, had to replace tube. Twice after rear flats, the car slid 180 degrees sideways on slick pavement. Hopefully this dangerous problem will be corrected. Before race, fire destroyed 1/2 of the array and damaged the chassis, preventing qualification at Phoenix. After repair the car was extremely reliable. Practiced 1689 kilometers (1050 miles) before the race.

Team Members: Arthur Chu, Bob Radicevich, Glen Bell, Paul Hickey, Jim Zahniser, Dale Morey, Matt Galielli, Kewan Siahatgar
Cost: $220,000
Project Time: 1 1/2 years.
Drag Coefficient Cd: 0.126
Frontal Area A: 1 m^2 (10.8 ft^2)
Drag Area CdA: 0.126 m^2 (1.36 ft^2) 3/8th scale model measured in Glen A. Martin Wind Tunnel at Maryland.

Qualifying Speed: 36.0 kph (22.4 mph) 34th
Avg. Race Speed: 32.0 kph (19.9 mph)
Best Daily Avg. Speed: 64.1 kph (39.8 mph)
Slowest Daily Avg. Speed: 16.3 kph (10.1 mph)
Daily Average Speed kph(mph):
1 37.26(23.16)
2 39.81(24.74)
3 37.43(23.26)
4 29.12(18.1)
5 16.25(10.1)
6 43.93(27.3)
7 64.04(39.8)

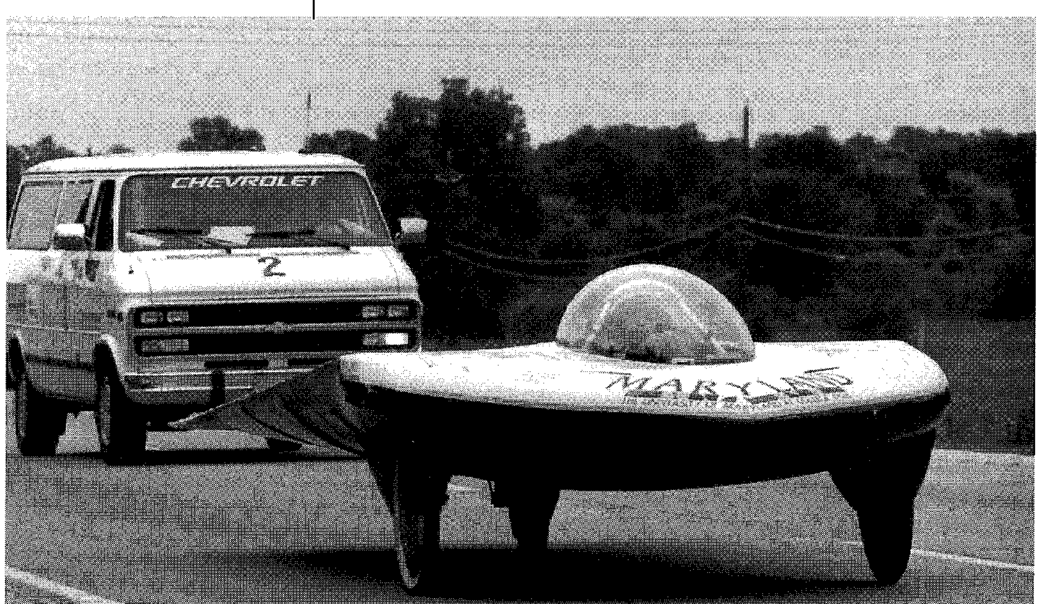
Weight w/o Driver: 320 kg (705 lbs)
Length: 6 m (19.7 ft)
Width: 2 m (6.6 ft)
Height: 1 m (3.3 ft)
Wheelbase: 1.98 m (6.5 ft)
Track Width: 1.65 m (5.41 ft)
Clearance: .31 m (1.01 ft)

Wheels and Tires: 48 spoke, 66 cm(26 in) wheels in front, 48 spoke/51 cm (20 in) in back. Wheels faired and covered; Avocet 4.8x66cm (1.9x26 in) front, 4.5x51 cm (1.75x20 in) back, slick tires 100 psi front, 120 psi back.
Number of Wheels: 3

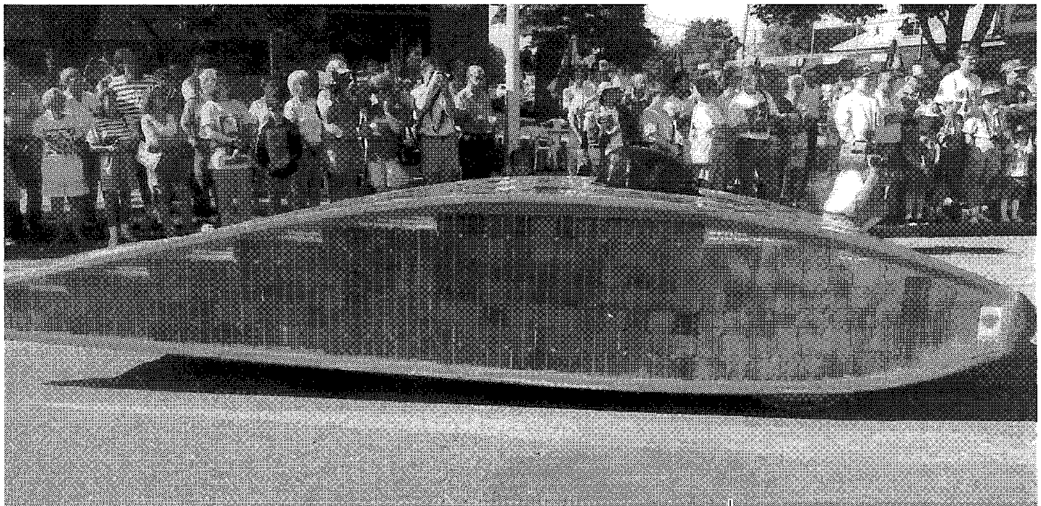
6th Place

Car: #2 - University of Maryland. "Pride of Maryland II". Department of Mechanical Engineering, College Park, MD 20742 (301) 405-5281, FAX (301) 314-9477
Time: 55.71 hrs **Avg. Speed:** 32.05 kph (19.92 mph)
Penalties: 6.51 hrs.
Days Finished Before 6:30 p.m.: 6
Total Distance: 1634.1 km (1015.6 mi)
Country: USA

Team Captain: Tony Nicolaidis.
Faculty Advisor: Dr. David Holloway



6th Place - University of Maryland



7th Place - University of Oklahoma

Est. Tire Rolling Resistance Coefficient: 0.0055
Number of Flat Tires During the Race: 0

Brakes, Suspension, and Steering: Hydraulic disk brakes front and back. Regenerative Braking. Double unequal A arm on front and rear trailing arm. Penske coil over air shocks. Rack and Pinion steering.
Chassis: Monocoque/Carbon/Nomex. Flat bars at suspension points for suspension attachment.
Motor: Uniq DR127S Brushless DC, 7.5kW rated,, 4400 RPM, 100 volts, 5.9 kg (13 lb) motor, 6.8 kg (15 lb) controller = 12.7 kg (28 lb) total. 85% efficient at operating power level, 85% peak. Fan cooling. Motor on rear trailing arm.
Controls and Instrumentation: Uniq motor controller. Constant speed cruise control. On board computer stores currents, voltages, temperatures, motor, panel, battery. Can down load data to external computer.
Transmission: Single reduction tooth belt, 3/1 to 5.25/1 ratios available.

Batteries: Optima, 7 batteries, 84 volts, 4.68 kWh, 55 ah, 127 kg (280 lb)
Battery Charge Each Day, Percent at Start/Finish:
1 100%/0%
2 20/0%
3 20/0%
4 20/0%.
5 10/0%
6 80/10%
7 100/0%
Solar Cells: Solarex Cells, Polycrystalline Silicon, 600 cells, 14% single cell rated efficiency, overall panel efficiency 12%, 1080 watts peak. 3 strings 3 AERL peak power trackers.

Type of Solar Panel: Fixed flat panel.
Panel Voltage: 150 volts
Reported Maximum Instantaneous Panel Power During Race: 1080 W
Reported Panel Power on a Sunny Day at High Noon: 900 W
Reported Average Panel Power From 8 a.m. to 5 p.m. During a Sunny Day: 700 W
Reported Speed on 750 watts of Panel Power: 48 kph (30 mph)

Notes and Reported Problems During the Race: Rear end accident broke four cells. Jumpered the cells, lost 2 volts from the panel. Brake lights failed, fixed. Rear trailing arm sheared, slid on fairing, 25 minutes to repair damage. Canopy fasteners failed, fixed. Two NACA air ducts underneath nose and dryer hose conducts air to driver and to battery fan. Had to cut 3 cm (1.18 in) off tail with Dremel tool to pass scrutineering. Had local Washington, DC, NBC Channel 4 weatherman, Eyad Atylah. Practiced only 2 weeks before the race.

7th Place

Car: #31—University of Oklahoma. "Spirit of Oklahoma II". EECS 200 Felgar #114, Norman, OK 73019 (405) 325-2969, FAX (405) 364-3666
Time: 64.31 hrs
Avg. Speed: 27.76 kph (17.25 mph)
Penalties: 9.403 hrs.
Days Finished Before 6:30 p.m.: 5
Total Distance: 1572.3 km (977.2 mi)
Country: USA

Team Captain: Stewart Mills.
Faculty Advisor: John E. Fagan
Team Members: Tod Hanley, Todd Cannon, Jim Henderson, Rich Swanstrom, Teresa Marks, Jung Kim, Dirk Nash, Bob Jameson, Peter Lillian.
Cost: $140,000
Project Time: 2 years.

Drag Coefficient, Cd: 0.15
Frontal Area A: 1.5 m^2 (16.2 ft^2)
Drag Area CdA: 0.22 m^2 (2.4 ft^2)
Estimated.

Qualifying Speed: 40.4 kph (25.1 mph), 21st
Avg. Race Speed: 27.8 kph (17.3 mph)
Best Daily Avg. Speed: 47.6 kph (29.6 mph)
Slowest Daily Avg. Speed: 17.1 kph (10.6 mph)
Daily Average Speed kph(mph):
1 31.79(19.76)
2 30.14(18.73)
3 36.93(22.95)
4 16.99(10.56)
5 20.82(12.94)

6 35.99(22.37)
7 47.61(29.59)
Weight w/o Driver: 205 kg (452 lb)
Length: 4.8 m (15.75 ft)
Width: 1.9 m (6.23 ft)
Height: 1.1 m (3.61 ft)
Wheelbase: 1.9 m (6.23 ft)
Track Width: 1.5 m (2.41 ft)
Clearance: 0.15 m (.49 ft)

Wheels and Tires: 36 spoke, 68.58 cm (27 in) front wheels with spoke covers; back—Specialized Trispoke wheel. Continental 68.58 cm x .79 in (27 in x 20 mm) tubular bicycle tires @ 150 psi
Number of Wheels: 3
Est. Tire Rolling Resistance Coefficient: 0.0050
Number of Flat Tires During the Race: 3

Brakes, Suspension, and Steering: Front hydraulic disk brakes, rear mechanical bicycle caliper emergency brakes MacPherson strut with rear trailing arm, coil springs, friction damping.Link steering.
Chassis: 6061-T6 Aluminum tubing space frame, 3.18 cm (1.25 in) OD, 1.24 cm (.049 in) wall. Body of carbon/.91 kg (2 lb) aluminum honeycomb sandwich construction.
Motor: Uniq DC brushless, 7.5 kW rated, 15 kW max, 3150 RPM, 90 volts, 15 amp, motor 3.63 kg (8 lb) controller 5.9 kg (13 lb) = 9.53 kg (21 lb) total, 86% efficient at operating power level. Blower cooling.
Controls and Instrumentation: Uniq motor controller with constant speed cruise control. 21 channel telemetry to chase van, sending current, voltage, temperature, etc.
Transmission: Single reduction belt drive, 7/1 to 9/1 pulleys.

Batteries: Panasonic, 8 batteries, 96 volts, 2.7 kWh, 48 ah, 79 kg(175 lb).
Solar Cells: BP Solar Cells, Monocrystalline Silicon, 1350 cells, 17% single cell rated efficiency, 980 watts peak, at 10:30 to 11:30 am or 1-2 pm. 850 watts with sun over head. 3 strings top, one on each side, 11 m² (118.8 ft²) total panel area. 5 AERL peak power trackers.

Type of Solar Panel: Top curved solar panel with cockpit near center of panel, 2 flat side panels. Panels covered with Mylar film.
Panel Voltage: 120 volts

Notes and Reported Problems During the Race: Collapsed rim on railroad track, tubular tire didn't blow. Practiced 1126.3 km (700 mi) before the race, 321.8 km (200 mi) in one day.

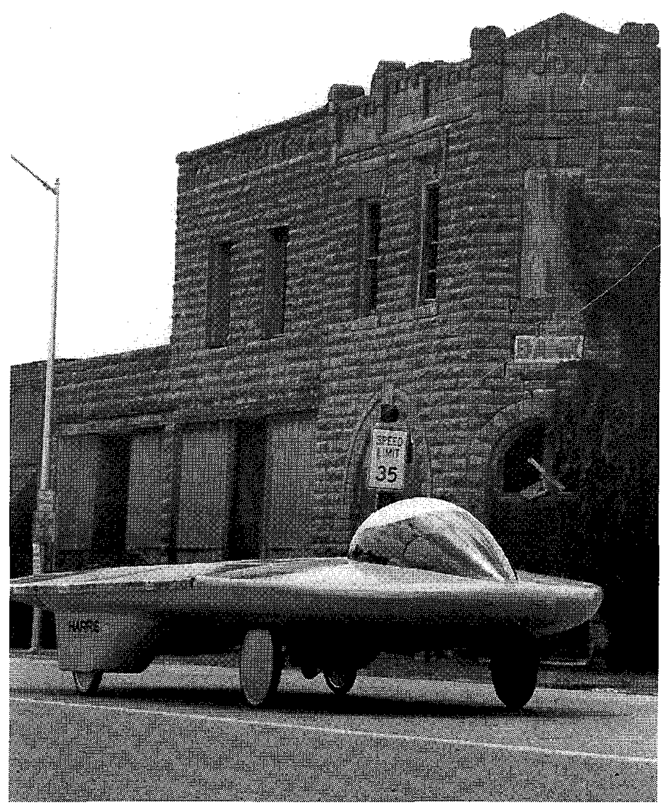
8th Place

Car: #413 - University of Massachusetts Lowell. "Spirit of Massachusetts" Dept. of Mechanical Engineering, Lowell, MA 01854 (508) 934-2968, FAX (508) 452-1445
Time: 66.66 hrs
Avg. Speed: 26.79 kph (16.65 mph)
Penalties: 15.517 hrs.
Days Finished Before 6:30 p.m.: 5
Total Distance: 1425 km (885.5 mi)
Country: USA

Team Captain: James Nelson.
Faculty Advisor: Dr. John Duffy
Team Members: M. Subhan Khan, Bill Lynch, Walter Vericker, Chris Beard, Batu Berkok, John Beaudoin, Chris Cooper, Pat Borzi, Paul Batcheller, John Kenney, Alan Rux, Mike Reinhardt, Guy Sliker, Adam Rux.
Cost: $45,000
Project Time: 1 year.

Drag Coefficient, Cd: 0.17
Frontal Area A: 1 m² (3.3 ft²)
Drag Area CdA: 0.17 m² (.56 ft²)
(EDS computer simulation).

Qualifying Speed: 39.6 kph (24.6 mph) 22nd
Avg. Race Speed: 26.9 kph, (16.7 mph)
Best Daily Avg. Speed: 50.7 kph (31.5 mph)
Slowest Daily Avg. Speed: 12.7 kph (7.91 mph)
Daily Average Speed kph(mph):
1 37.52(23.32)
2 34.71(21.57)
3 36.64(22.77)
4 19.29(11.99)
5 12.73(7.91)



8th Place - University of Massachusetts Lowell

9th Place - Kauai Community College

6 42.51(26.42)
7 50.64(31.47)

Weight w/o Driver: 352 kg (775 lb)
Length: 6 m (19.69 ft)
Width: 2 m (6.6 ft)
Height: 1.1 m (3.6 ft)
Wheelbase: 2.5 m (8.2 ft)
Track Width: 1.5 m (4.9 ft) fr., 1.6 m (5.25) ba.
Clearance: 0.30 m (.98 ft)

Wheels and Tires: Milled aluminum wheels 8 spokes with covers and fairings; Rledge 4 cm x 51 cm (1.75 x 20 in) treaded tires @ 100 psi
Number of Wheels: 4
Est. Tire Rolling Resistance Coefficient: 0.0055
Number of Flat Tires During the Race: 2

Brakes, Suspension, and Steering: Suzuki ATV Hydraulic disk front and back brakes, Regenerative Brake. Double A arm front, trailing arm rear, Risse Racing Technology gas shocks. Rack and pinion steering.
Chassis: 4130 chrome-moly steel tubing space frame with Kevlar/ foam sandwich body shell.
Motor: Solectria BRLS 11 DC brushless, 7.5 kW rated, 15 kW max, 7500 RPM, 150 volts, 8.2 kg (18.1 lb), 90% efficient at operating power level, 94% peak efficiency. Blower cooling.
Controls and Instrumentation: Display of speed, distance, buss voltage, panel voltage and current, battery AH meter.
Transmission: Single reduction chain, 7/1 ratio.

Batteries: Sears, 12 batteries, 144 volts, 4.9 kWh, 33 ah, 113.4 kg (250 lb).
Battery Charge Each Day, Percent at Start/Finish:
1 100/20%
2 60/10%
3 50/5%
4 50/0%.
5 7/90%
6 95/25%
7 95/30%

Solar Cells: BP Solar Cells, Monocrystalline Silicon, 820 cells, 17% single cell rated efficiency, panel efficiency in operation only 12%, 1100 watts peak. 4 student designed and constructed peak power trackers (Paul Batcheller).

Type of Solar Panel: Fixed, gently curved inverted trough shape.
Panel Voltage: 100 volts
Reported Maximum Instantaneous Panel Power During Race: 1360 W
Reported Panel Power on a Sunny Day at High Noon: 950 W
Reported Speed on 1000 Watts of Panel Power: 66 kph (41 mph)

Notes and Reported Problems During the Race: BP solar cells were lower efficiency than rated, and there were a few bad strings. The digital meters had a noise problem and were difficult to read. The drive chain had to be tightened daily. The peak power trackers designed and built by students were reliable throughout the race. Practiced only 16.1 km (10 mi) before race.

9th Place

Car: #8 - Kauai Community College. "Ka'a La O Kaua'i". 3-1901 Kaumualii Highway, Lihue, HI 96766 (808) 245-8239, FAX (808) 245-8220
Time: 66.88 hrs
Avg. Speed: 25.92 kph (16.11 mph)
Penalties: 12.323 hrs.
Days Finished Before 6:30 p.m.: 3
Total Distance: 1497.8 km (930.9 mi)
Country: USA

Team Captain: Eric Eichholz.
Faculty Adivsors: Ralph Kouchi, Rick Matsumura, Marshall Mock, Charles Yamamoto, Francis Takahashi, Skip Templeton, Tracy Tucker.
Team Members: Jason Alfiler, Darren Machado, Danny Miyasato, Anthony Agiar, Elia Kanahele, Kealii Kanahele, Jason Matsuoka, Zane Abreu, David Miyasato, Kamela Robinson, Celeste Miyashiro, Robert Yoro, Victor Bigno, Nester Melchor.
Cost: $90,000
Project Time: 2 years.

Drag Coefficient Cd: 0.20
Frontal Area A: 1.2 m^2 (13 ft^2)
Drag Area CdA: 0.24 m^2 (2.59 ft^2) 1/4 scale model mounted on scale on back of a pick up truck used to measure drag. Tufts were used to visualize flow.

Qualifying Speed: 39.9 kph (24.8 mph) 30th
Avg. Race Speed: 25.9 kph (16.1 mph)
Best Daily Avg. Speed: 44.2 kph (27.5 mph)
Slowest Daily Avg. Speed: 16.3 kph (10.1 mph)
Daily Average Speed kph(mph):
1 38.47(23.91)
2 27.88(17.33)
3 29.14(18.11)
4 19.39(12.05)
5 16.28(10.12)
6 30.97(19.25)
7 44.23(27.49)

Weight w/o Driver: 303 kg (668 lbs)
Length: 5.95 m (19.52 ft)
Width: 2 m (6.6 ft)
Height: 1.07 m (1.72 ft)
Wheelbase: 2.9 m (4.7 ft)
Track Width: 1.42 m (4.66 ft) fr., .25 m (.82 ft) ba.
Clearance: 0.2 m (.66 ft)

Wheels and Tires: 36 spoke, 51 cm (20 in) wheels with spoke covers; Avocet 51 cm x 4 cm (20 x 1.75 in) slick tires @ 100 psi
Number of Wheels: 4, (2 close together in back)
Est. Tire Rolling Resistance Coefficient: 0.0055
Number of Flat Tires During the Race: —

Brakes, Suspension, and Steering: Hydraulic disc go cart brakes/duel master cylinder, Double A arm front, swing arm back, Works Performance motor cycle shocks, nitrogen filled, coil over shock. Rack and pinion steering.
Chassis: Welded titanium tubing 2.5 cm (1 in)/ 3.18 cm (1.25 in), .14 cm (.056 in) wall. Stress relieved. Carbon/foam sandwich body.
Motor: Solectria DC brushless, 7.5 kW rated, 15 kW max, 6000 RPM, 84 volts, 11.8 kg (26 lb), 90% efficient at operating power level. Blower cooling.
Control and Instrumentation: Integrating microprocessor on board to determine battery ampere hours and monitor voltage, current, temperature, etc. LCD display. Current limited constant speed control. Telemetry to chase van.
Transmission: Single reduction chain with 5/1 ratio.

Batteries: Trojan, 8 batteries, 96 volts, 4.8 kWh, 50 ah, 112 kg (248 lb).
Solar Cells: BP Cells, Monocrystalline Silicon, 774 cells, 17% single cell rated efficiency, overall panel efficiency 13.5%, 900 watts peak. 36 modules. 2 AERL peak power trackers. 48.3 kph (30 mph) on 1000 watts input to motor.

Type of Solar Panel: Fixed flat panel.
Panel Voltage: 210 volts

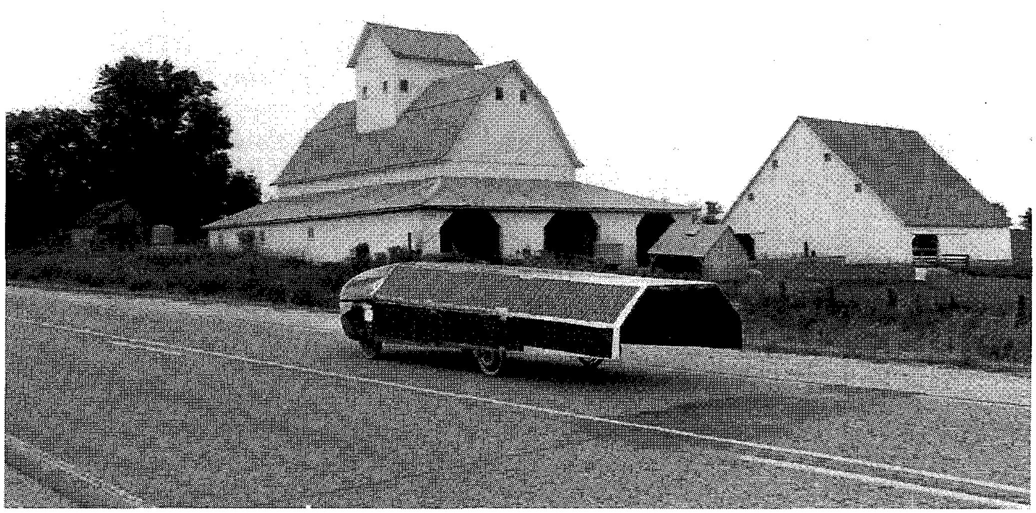
Notes and Reported Problems During the Race: Broke rear trailing arm on Day 2. Repaired by welding (local welder), lost 3 hours. Minor problems in voltage and current display, corrected by reset. Practiced 322 km (200 mi) before race.

10th Place

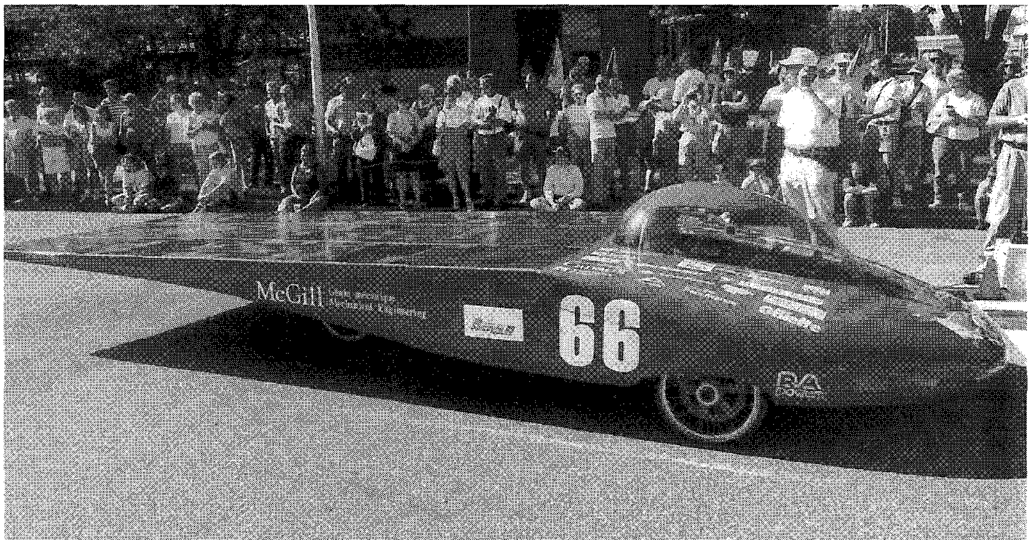
Car: #9 - Iowa State University. "PrISUm II". Chemical Engineering Dept., 306 Sweeney Hall, Ames, IA 50011-2230 (515) 294-4959, FAX (515) 294-2689
Time: 70.30 hrs
Avg. Speed: 25.39 kph (15.78 mph)
Penalties: 15.657 hrs.
Days Finished Before 6:30 p.m.: 5
Total Distance: 1618.5 km (1005.9 mi)
Country: USA

Team Captains: Matt McGuire, Doug Welsh
Faculty Advisors: Dr. James C. Hill, William James, Alan Potter, Charles Burg, Scott Ocken
Team Members: Scott Thompson, Matt McGuire, Julia McGuire, Matthew McGuire, Jeff Osborn, Bryan Arnold, Kevin Anderson, David Eggert, Todd Hanssen, Terry Herrman, Russell Hubrich, Andy Kurriger, Chad Lingenfelder, Jim O'Halloran, Deven Patel, Gregory Taylor, Monte Taylor, Douglas Welsh, Ryan Miller, Scott Pringle, Todd Seelhammer
Cost: $200,000
Project Time: 14 months

Drag Coefficient, Cd: 0.16
Frontal Area A: 1.25 m^2 (13.5 ft^2)
Drag Area CdA: 0.20 m^2 (2.16 ft^2) 1/8th scale model, measured ISU Wind Tunnel.



10th Place - Iowa State University



11th Place - McGill University

Qualifying Speed: 46.5 kph (28.9 mph), 10th
Avg. Race Speed: 25.4 kph (15.8 mph)
Best Daily Avg. Speed: 46.2 kph (28.7 mph)
Slowest Daily Avg. Speed: 15.1 kph (9.4 mph)
Daily Average Speed kph(mph):
1 33.58(20.87)
2 26.5(16.47)
3 33.85(21.04)
4 16.75(10.41)
5 15.12(9.40)
6 38.92(24.19)
7 46.13(28.67)

Weight w/o Driver: 400 kg (882 lb)
Length: 6 m (19.69 ft)
Width: 1.8 m (5.9 ft)
Height: 1.2 m (3.94 ft)
Wheelbase: 2.5 m (8.2 ft)
Track Width: 1.5 m (4.9 ft)
Clearance: 0.25 m (.82 ft)

Wheels and Tires: 36 spoke, 51 cm (20 in) wheels with spoke covers; Avocet Fasgrip 51 cm x 4 cm (20 x 1.75 in) slick tires @ 100 psi
Number of Wheels: 4
Est. Tire Rolling Resistance Coefficient: 0.0055
Number of Flat Tires During the Race: 1

Brakes, Suspension, and Steering: Front center pull cantilever caliper mountain bike brakes, hydraulic Airhart disc brakes on back. Regenerative Brakes. Front Trek DDS modified mountain bike fork with added 100 lb/in springs on each fork. Trailing arm back, with Works Performance coil over gas shock. Ackerman/cable steering.
Chassis: Hybrid space frame/monocoque frame. Driver cage 6061-T6, 2.5 cm (1 in) aluminum tubing with .16 cm (1/16 in) wall. Body— Kevlar/Nomex/foam/carbon honeycomb in a load specific designed structure.

Motor: Solectria DC brushless, 7.5 kW rated, 14 kW max, 6500 RPM, 120 volts, 18.6 kg (41 lb) with controller, 90% efficient at operating power level, 94% peak efficiency.
Controls and Instrumentation: Constant speed cruise control. Cockpit display of speed, distance, motor amps and volts, motor temperature, panel voltage, panel current, battery voltage, and integrated ampere hours.
Transmission: Direct drive, 2.5 cm (1 in) cog belt, 5/1 to 8/1 ratios, custom drive wheel.

Batteries: Genesis, 10 batteries, 120 volts, 4.56 kWh, 38 ah, 150 kg (330 lb)
Solar Cells: BP Solar Cells, Monocrystalline Silicon, 1561 cells, 17% single cell rated efficiency, overall panel efficiency 13%. 3 strings on top, 3 strings on side, 5 individual facets. 9 student designed and constructed peak power trackers. (Master's project, Paul). 5 times faster and 98% efficient. Peak panel output 1100 watts.

Type of Solar Panel: Five flat facets, wrapping around frame. Panels are removeable, so they may face sun for charging. Speed on 1000 watts = 51 kph (32 mph).

Notes and Reported Problems During the Race: Second day hit railroad tracks, bent frame, broke shocks, had to trailer in. Replaced batteries on Day 4 which permitted car to finish 1st on Day 5. Battery/time penalty was less than the mileage/time penalty would have been. Practiced 241 km (150 mi) before race.

11th Place

Car: #66 - McGill University. "Ra Power". 817 Sherbrooke Street W., Montreal, Quebec Canada H3A 2K6 (514) 398-7259, FAX (514) 398-7379
Time: 70.58 hrs
Avg. Speed: 25.29 kph (15.72 mph)
Penalties: 14.887 hrs.
Days Finished Before 6:30 p.m.: 5
Total Distance: 1442.2 km (896.2 mi)
Country: Canada

Team Captains: Joey Mennitto, Pedro Gregorio, Mike Mastrogiacomo
Faculty Advisor: Professor Larry Lessard
Team members: Mike Mastrogiacomo, Joe Diliello, Joanis Louloudakis, Bruce Hill, Gary Savard, Bobby Inak, Dwayne Tsang, Joey Mennitto, Gary Savard, Paul Trolio, Patrick Gregoire, Pedro Gregorio, Tommy Marincic
Cost: Can$150,000
Project Time: 2 1/2 years.

Drag Coefficient, Cd: 0.13
Frontal Area A: 1.3 m^2 (14.04 ft^2)
Drag Area CdA: 0.169 m^2 (1.83 ft^2) Measured 1/10 scale model at McGill.
Qualifying Speed: 39.4 kph (24.5 mph), 25th
Avg. Race Speed: 25.3 kph (15.7 mph)
Best Daily Avg. Speed: 48.4 kph (30.1 mph)
Slowest Daily Avg. Speed: 15.1 kph (9.4 mph)
Daily Average Speed kph(mph):
1 33.06(20.55)
2 31.12(19.34)
3 33.34(20.72)
4 15.12(9.39)
5 16.23(10.09)
6 33.48(20.81)
7 48.36(30.06)

Weight w/o Driver: 288 kg (635 lb)
Length: 6 m (19.7 ft)
Width: 2 m (6.6 ft)
Height: 1.1 m (3.6 ft)
Wheelbase: 2.45 m (8.04 ft)
Track Width: 1.85 m (6.07 ft)
Clearance: 0.15 m (0.49 ft)

Wheels and Tires: 48 spoke, 51 cm (20 in) wheels without spoke covers; ACS 51 cm x 4 cm (20 x 1.75 in) lightly treaded tires @ 100 psi
Number of Wheels: 4 (2 narrowly spaced in back).
Est. Tire Rolling Resistance Coefficient: 0.0055
Nmber of Flat Tire During the Race: 3

Brakes, Suspension, and Steering: Enginetics disk front brakes, mountain bike caliper brakes rear, regenerative brake. MacPherson struts front, trailing arm rear. Coil over pneumatic shock front, coil over Honda motor cycle shock rear. Rack and Pinion steering.
Chassis: Welded aluminum tube space frame with Kevlar body.
Motor: Solectria DC brushless, 6 kW rated, 12 kW max, 6000 RPM, 120 volts, 100 amps, 11.8 kg (26 lb), 90% efficient at operating power level, 94% peak efficiency. Blower cooling.
Controls and Instrumentation: Constant speed cruise control. Telemetry to chase vehicle computer/simulator to give race strategy.
Transmission: Direct Gates belt reduction, 7/1 ratio.

Batteries: Gill, 5—24V batteries, 120 volts, 3.23 kWh, 18 ah, 91 kg (200 lb)
Solar Cells: Astro Power Cells, 741 cells, 12 1/2% single cell rated efficiency, 940 watts peak. 3 strings on flat panel. 1 Solectria peak power tracker. 64.36kph (40 mph) on 1000 watts input to motor.
Type of Solar Panel: Fixed flat panel, 940 watts peak power output
Panel Voltage: 100 volts.

Notes and Reported Problems During the Race: Cruise control stuck. Rear flats take 8 1/2 minutes to change. Low battery on cloudy days. Rough road damaged pneumatic shocks on front suspension, causing the tires to scrub and wasting energy, replaced on day 6. Practiced 193 km (120 mi) before race.

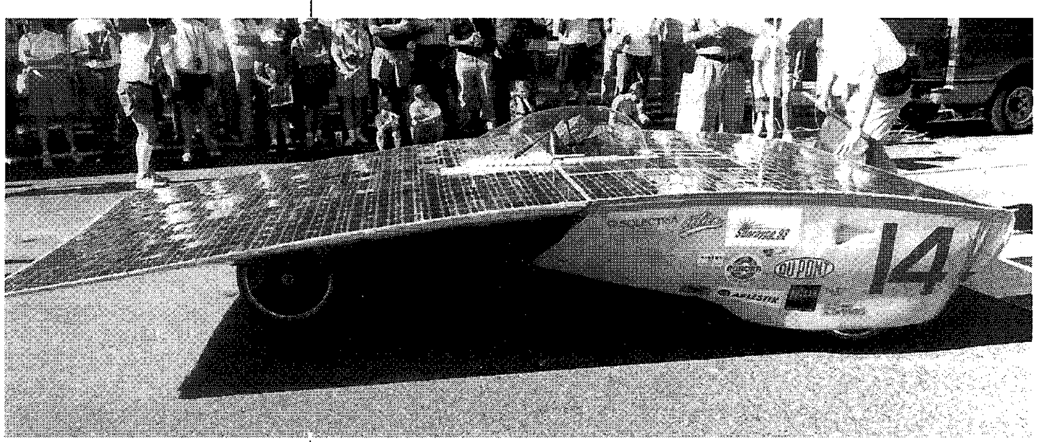
12th Place

Car: #14—California State University, Fresno. "Sun Shark". Mech. Eng. Dept., 2220 E. San Ramon, Fresno, CA 93740-0015 (209) 278-2238, FAX (209) 278-7621
Time: 75.51 hrs
Avg. Speed: 23.64 kph (14.69 mph)
Penalties: 18.387
Days Finished Before 6:30 p.m.: 3
Total Distance: 1361.8 km (846.2 mi)
Country: USA

Team captain: Robert A. Taylor
Faculty Advisor: Dr. John A. Seevers
Team members: Sam Traxinger, Terry Thompson, Luke LaBorde, Brett Meek, Dewey Day, Kin Sing Yen, Tlamelo Nkoane, Tim Rasmussen
Cost: $40,000
Project Time: 1 1/2 years

Drag Coefficient, Cd: 0.17
Frontal Area A: 1.2 m^2 (13 ft^2)
Drag Area CdA: 0.20 m^2 (2.16 ft^2) (est.)

Qualifying Speed: 65.8 kph (40.9 mph), 9th
Avg. Race Speed: 23.6 kph (14.7 mph)
Best Daily Avg. Speed: 44.5 kph (27.7 mph)
Slowest Daily Avg. Speed: 15.9 kph (9.9 mph)
Daily Average Speed kph(mph)
1 26.77(16.64)
2 15.91(9.89)
3 33.82(21.02)



12th Place - California State University, Fresno

13th Place - Arizona State University

4 16.8(10.44)
5 21.85(13.58)
6 34.43(21.40)
7 44.49(27.65)

Weight w/o Driver: 257 kg (567 lbs)
Length: 4.45 m (1.17 ft)
Width: 2 m (6.6 ft)
Height: 1 m (3.3 ft)
Wheelbase: 2.4 m (7.87 ft)
Track Width: 1.5 m (4.92 ft)
Clearance: 0.18 m (.59 ft)

Wheels and Tires: 48 spoke, 51 cm (20 in) wheels with spoke covers; Avocet 51 cm x 3 cm (20 x 1.25 in) slick tires @ 90 psi
Number of Wheels: 3
Est. Tire Rolling Resistance Coefficient: 0.0055
Number of Flat Tires During the Race: 1

Brakes, Suspension, and Steering: GNB front hydraulic disc brakes. Rear cable, mountain bike hydraulic caliper brakes. Regenerative brakes. MacPherson strut, piston hydraulic shock with inner spring. Rear trailing arm. with custom coil over shock. Rack and Pinion steering.
Chassis: 4135 chrome-moly tubing space frame, .64 cm (.25 in)—3.8 cm (1.5 in) tubing, .089 cm (.035 in) wall. Kevlar/aluminum honeycomb sandwich fairing. Tail is aluminum rib and spar with aluminum skin.
Motor: Solectria BRLS8 DC brushless, 7.7 kW rated, 15 kW max, 6000 RPM, 120 volts, 11.8 kg (26 lb), 90% efficient at operating power level, 94% peak efficiency.

Controls and Instrumentation: Constant speed control.
Transmission: Two motor speeds by switching the field from parallel to series. Direct drive Gates cog belt, 4.4/1 ratio.

Batteries: GNB, 10 batteries, 120 volts, 4.8 kWh, 20 ah, 101 kg (223 lb)
Battery Charge Each Day, Percent at Start/Finish:
1 100%/0%
2 70/30%
3 70/30%
4 70/30%.
5 60/0%
6 70/35%
7 65/35%
Solar Cells: Siemens solar cells, Monocrystalline Silicon, 700 cells, 14% single cell rated efficiency, 10% overall panel efficiency. 1000 watts peak. 2 strings. 2 AERL peak power trackers.

Type of Solar Panel: Fixed 2D gently curved flat panel.
Panel Voltage: 120 volts
Reported Maximum Instantaneous Panel Power During Race: 1000 W
Reported Panel Power on a Sunny Day at High Noon: 700 W
Reported Average Panel Power From 8 a.m. to 5 p.m. During a Sunny Day: —
Reported Speed on 600 Watts of Panel Power: 45kph (28 mph)

Notes and Reported Problems During the Race: Due to bad instrumentation, on the first day the solar array failed undetected, draining battery. Panel failed due to a broken wire and short. The panel is not easy to tilt for stationary charging and not good in a side sun—a poor design. Constant problems with instrumentation and communications. Minor leak in front shock, had to add oil. Practiced 97 km (60 mi) before race.

13th Place

Car: #45—Arizona State University. "Solar Phoenix". College of Eng. & Applied Sciences, Tempe, AZ 85287-5806 (602) 965-2896, FAX (602) 965-8296
Time: 78.07 hrs
Avg. Speed: 22.87 kph (14.21 mph)
Penalties: 20.61 hrs.
Days Finished Before 6:30 p.m.: 3
Total Distance: 1290 km (801.6 mi)
Country: USA

Team captain: Nick Gilbert.
Faculty Advisor: Byard D. Wood
Team member: Dave Haugan

Cost: $30,000
Project Time: 1 year.

Qualifying Speed: 70.6 kph (43.9 mph), 23rd
Avg. Race Speed: 22.9 kph, (14.2 mph)
Best Daily Avg. Speed: 41.3 kph (25.7 mph)
Slowest Daily Avg. Speed: 12.8 kph (8.0 mph)
Daily Average Speed kph(mph):
1 36(22.38)
2 24.9(15.48)
3 25.49(15.84)
4 17.36(10.79)
5 12.79(7.95)
6 31.47(19.56)
7 41.3(25.67)

Weight w/o Driver: 354 kg (781 lb)
Length: 5 m (16.4 ft)
Width: 2 m (6.6 ft)
Height: 1.1 m (3.6 ft)
Wheelbase: 2.3 m (7.5 ft)
Track Width: 1.5 m (4.92 ft)
Clearance: 0.2 m (0.66 ft)

Wheels and Tires: 36 spoke, 66 cm (26 in) front and 36 spoke, 51 cm (20 in) back wheels with spoke covers; front—Avocet 66 cm x 3 cm (26 x 1.25 in) and Avocet 51cm x 4.4 cm (20 x 1.75 in) rear, both slick tires @ 100 psi
Number of Wheels: 3
Est. Tire Rolling Resistance Coefficient: 0.0050/0.0055
Number of Flat Tires During the Race: 2

Brakes, Suspension, and Steering: Airhart hydraulic disc brakes front and rear. Rear cable/hydraulic Pro Stop mountain bike emergency disc brakes, regenerative brake. Front double A arm, rear trailing arm, coil over shocks. Rack and Pinion steering.
Chassis: 6061-T6 Aluminum tubing space frame. Body, foam bulkheads and stringers with shaped foam exterior covered with fiberglass. Kevlar/Nomex/fiberglass array.
Motor: Solectria BRLS8 DC brushless, 6kW rated, 12kW max, 6000 RPM, 96 volts, 15 amps/30 amps max., 11.8 kg (26 lb), 90% efficient at operating power level, 94% peak efficiency.
Controls and Instrumentation: BRLS 100 Solectria motor controller. Switchable series/parallel, 2/1 speed ratio. Constant throttle position speed control. All important controls are compactly mounted on steering wheel. Telemetry of speed, RPM, voltage, currents, temperatures, etc. to chase van.

Transmission: 2/1 motor speed ratio, and direct cog belt drive, 5.3/1 reduction.
Batteries: Trojan, 8 batteries, 96 volts, 4.95 kWh, 53 ah, 111 kg (245 lb). On board AH integrator to monitor battery charge.
Solar Cells: Siemens solar cells, Monocrystalline Silicon, 800 cells, 7.7 m^2 (83.2 ft) panel area, panel surrounds cab. 14% single cell rated efficiency, overall panel efficiency 12%, 750 watts peak. 5 Sun Amp peak power trackers.

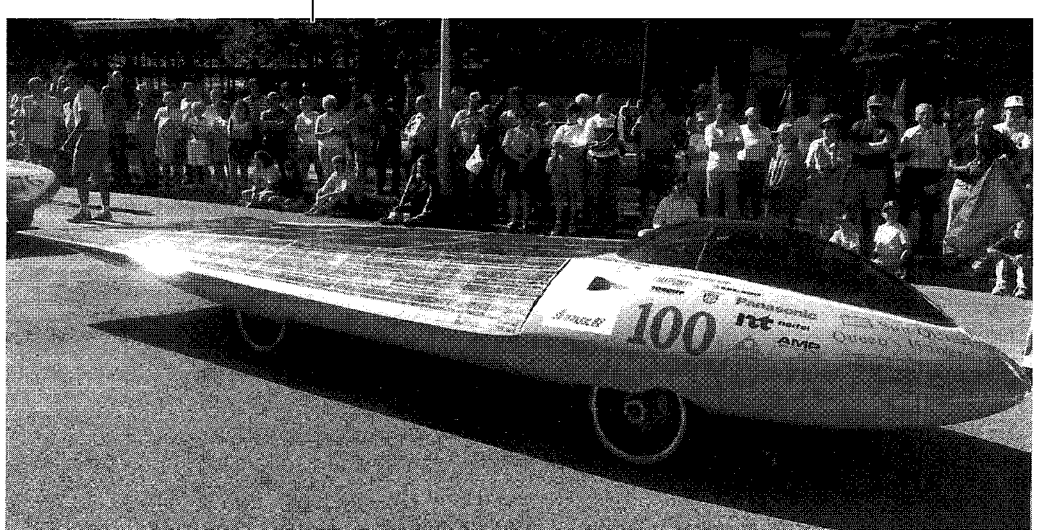
Type of Solar Panel: Fixed 2D curved panel conforming to aero-shape.
Panel Voltage: 150 volts

Notes and Reported Problems During the Race: First day peak power tracker failure, loose wire, bad instrumentation. Low batteries second through fifth day. Steering wheel has finger tip controls for throttle, regenerative brake, cruise control, turn signal, windshield wiper, switch to display speed, volts and amps. Practiced 97 km (60 mi) before race.

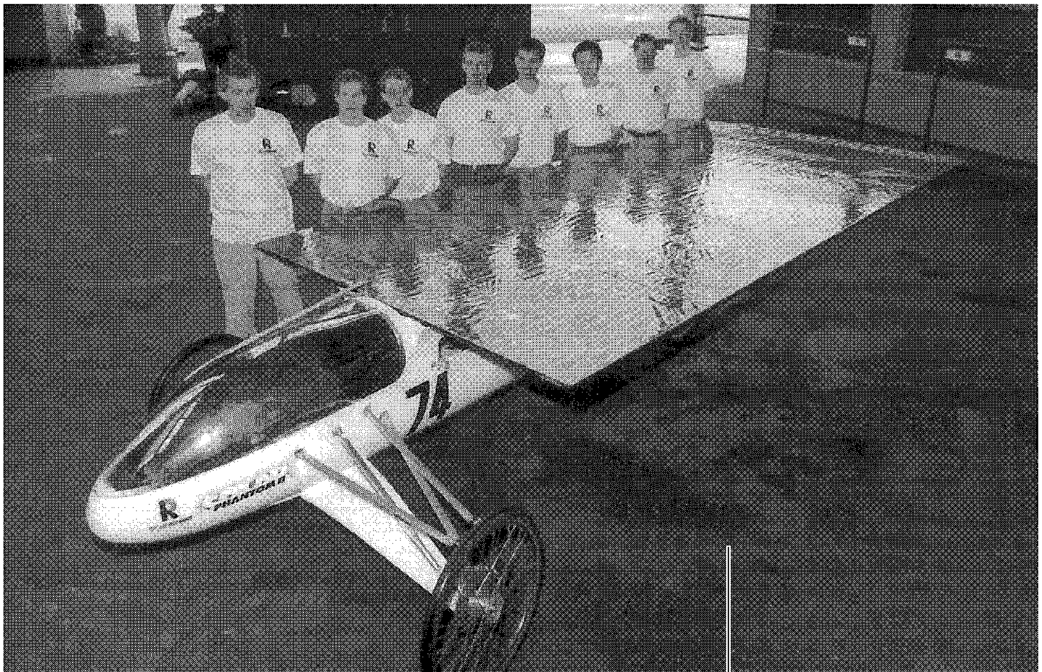
14th Place

Car: #100—Queens University. "Sun QUEST II". Dept. of Mech Eng., Dept. of Elec. Eng., Kingston, Ontario, Canada K7L 3N6 (613) 545-6682, FAX (613) 545-6489
Time: 78.25 hrs
Avg. Speed: 22.82 kph (14.18 mph)
Penalties: 19.81 hrs.
Days Finished Before 6:30 p.m.: 2
Total Distance: 1331 km (827.2 mi)
Country: Canada

Team Captain: Andrew Marchant
Faculty Advisor: Dr. Stephan J. Harrison
Team Members: Mark Day, Alan Lysne, Matt Pringle, Shelly Lewis, Dana Detlor, Grant Freeman, Paul Puazé, Dave Unrau, Edward Buiel, T.J. Parass, Ian McLeod, Richard Zakrzewski, Lisa Chin-A-Young, J. Alex Moore, Clement Lam, James Forest.



14th Place - Queens University



15th Place - Rose Hulman Institute of Technology

Cost: Can$100,000
Project Time: 16 months.

Drag Coefficient, Cd: 0.24
Frontal Area A: 1.1 m^2 (11.9 ft^2)
Drag Area CdA: 0.26 m^2 (2.81 ft^2) Measured full scale in the National Research Council of Canada Wind Tunnel in Ottawa.

Qualifying Speed: 37.4 kph (23.2 mph), 29th
Avg. Race speed: 22.8 kph (14.2 mph)
Best Daily Avg. Speed: 36.1 kph (22.4 mph)
Slowest Daily Avg. Speed: 15.8 kph (9.8 mph)
Daily Average Speed kph(mph)
1 31.09(19.32)
2 23.52(14.62)
3 22.09(13.73)
4 18.71(11.63)
5 15.74(9.78)
6 28.67(17.82)
7 36.11(22.44)

Weight w/o Driver: 356 kg (785 lbs)
Length: 6 m (19.7 ft)
Width: 2 m (6.6 ft)
Height: 1 m (3.3 ft)
Wheelbase: 2.4 m (7.9 ft)
Track Width: 1.25 m (4.1 ft)
Clearance: 0.3 m (1 ft)

Wheels and Tires: 36 spoke, 51 cm (20 in) wheels with spoke covers; Avocet 51 x 4 cm (20 x 1.75 in) Freestyle tires @ 110 psi
Number of Wheels: 4
Est. Tire Rolling Resistance Coefficient: 0.0055

Number of Flat Tires During the Race: 1

Brakes, Suspension, and Steering: Enginetics front hydraulic disk, Pro Stop mountain bike hydraulic disc brake rear. Twin A arm front, trailing arm rear, 225 lb./in coil springs over gas shocks, rear. 420 lb/in coil over shocks, front.. Rack and Pinion steering to push/pull cable moves tie rods.
Chassis: 6061-T6 Aluminum and Duralcan tubing space frame, 2.5 cm (1 in)/3 cm (1.25 in) x .32 cm (.13 in) wall. Kevlar/Nomex/Derakaine body, 470 resin.
Motor: Solectria DC brushless, 6 kW rated, 12 kW max, 4000 RPM, 72 volts, 110 amps. max, 11.3 kg (25 lb), 90% efficient at operating power level, 94% peak efficiency. Blower cooling.
Controls and Instrumentation: Telemetry of car operating data to lead vehicle computer.
Transmission: Series parallel switch on motor gives 2/1 speed reduction. Direct drive, 5/1 speed reduction.

Batteries: Panasonic, 6 batteries, 72 volts, 4.8 kWh, 65 ah, 111 kg (244 lb)
Battery Charge Each Day, Percent at Start/Finish:
1 100/30%
2 70/10%
3 65/0%
4 20/0%.
5 35/0%
6 45/0%
7 55/0%
Solar Cells: Kyocera solar cells, Polycrystalline Silicon, 764 cells, 12 1/2 % single cell rated efficiency, panel 9% efficient in operation. 900 watts peak. 3 facets, 4 strings. 3 Solectria peak power trackers.

Type of Solar Panel: Fixed panel with a three gently warped facets, two side and one top. **Panel Voltage**: 53 volts top, 31 volts side.
Reported Maximum Instantaneous Panel Power During Race: 850 W **Reported Panel Power on a Sunny Day at High Noon**: 750 W
Reported Average Panel Power From 8 a.m. to 5 p.m. During a Sunny Day: 450 W
Reported Speed on 960 Watts of Panel Power: 55 kph (34 mph)

Notes and Reported Problems During the Race: Low batteries from Day 2 through Day 6, prevented finish by 6:30 pm. Frequent spoke breakage. Chain fell off twice. Broke cells while trailering. Water damage to cab alpha-numeric display (repaired). This was a centennial year project, 100 years of engineering at Queens. The vehicle was 100% designed and built at the University by undergraduate students. Team purpose focuses equally on education and promotion of solar vehicle technology and on construction. Practice 756 km (470 miles) before race.

15th Place

Car: #74 - Rose-Hulman Institute of Technology. "Solar Phantom II". 5500 Wabash Avenue, Box 1723, Terre Haute, IN 47803 (812) 877-8457, FAX (812) 877-8121
Time: 79.69 hrs
Avg. Speed: 22.40 kph (13.92 mph)
Penalties: 22.487 hrs.
Days Finished Before 6:30 p.m.: 2
Total Distance: 1258.8 km (782.2 mi)
Country: USA

Team Captains: David W. Balley, Dylan Schickel
Faculty Advisor: Dr. Jovan Lebaric
Team Members: Ed Stacy, Jonathan Rich, Jeff Kwok, Eric Wandell, Chip Montgomery, Marc Bouton, Eric Collins, Greg Halnes, Greg Hubbard, Trent Newton, Chad Richardson, Ron White, Howard Wong, Mark Ziegler.
Cost: $59,000
Project Time: 14 months.

Drag Coefficient, Cd: 0.45
Frontal Area A: .45 m² (4.86 ft²)
Drag Area CdA: 0.21 m² (2.27 ft²) 1/5th scale wind tunnel model, plus estimates from power vs. speed curves.

Qualifying Speed: 53.2 kph (33.1 mph), 13th
Avg. Race Speed: 22.4 kph (13.9 mph)
Best Daily Avg. Speed: 45.6 kph (28.3 mph)
Slowest Daily Avg. Speed: 15.7 kph (9.8 mph)
Daily Average Speed kph(mph)
1 23.04(14.32)
2 20.88(12.98)
3 25.7(15.97)
4 17(10.57)
5 15.66(9.73)
6 34.61(21.51)
7 45.55(28.31)

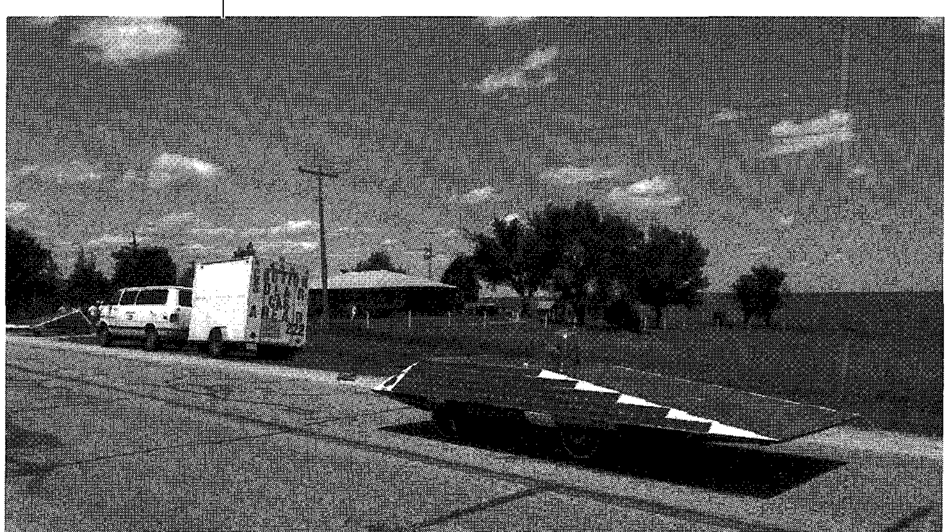
Weight w/o Driver: 298 kg (658 lbs)
Length: 5.5 m (18.05 ft)
Width: 2 m (6.6 ft)
Height: 1.02 m (3.35 ft)
Wheelbase: 2.7m
Track Width: 1.9m
Clearance: 0.38 m (1.25 ft)
Wheels and Tires: Front—36 spoke, 66 cm (26 in) wheels with spoke covers. Continental Avenue, 66 x 4 cm (26 x 1.75 in) slick tires @ 110 psi front. Rear, Perelli HT1TT motor cycle tire, @ 42 psi with rear wheel fairing.
Number of Wheels: 3
Est. Tire Rolling Resistance Coefficient: 0.0050/.0075
Number of Flat Tires During the Race: 0

Brakes, Suspension, and Steering: Hayes industrial disk front brakes, motorcycle drum brake rear Cable actuated mountain bike emergency brake. Regenerative Brake. Front transverse S glass leaf spring with custom dampers. Rear trailing arm, with Firestone air spring. Aluminum rack and pinion steering.
Chassis: Carbon//aluminum honeycomb monocoque body.
Motor: Uniq Mobility DR127S, 7.5 kW rated, 4000 RPM, 100 volts, 6 kg (13 lb), 85% efficient at operating power level. Blower cooling.
Controls and Instrumentation: Uniq CR10/100 motor controller. No Telemetry, on board instrumentation only. Microprocessor integrates current and voltage to give batter ampere hours.
Transmission: Custom Dana Corp 2 speed transmission (2/1 reduction), #35 ANSI chain drive transmission to rear wheel with go cart sprockets. HPR cog belt drive, motor to transmission.

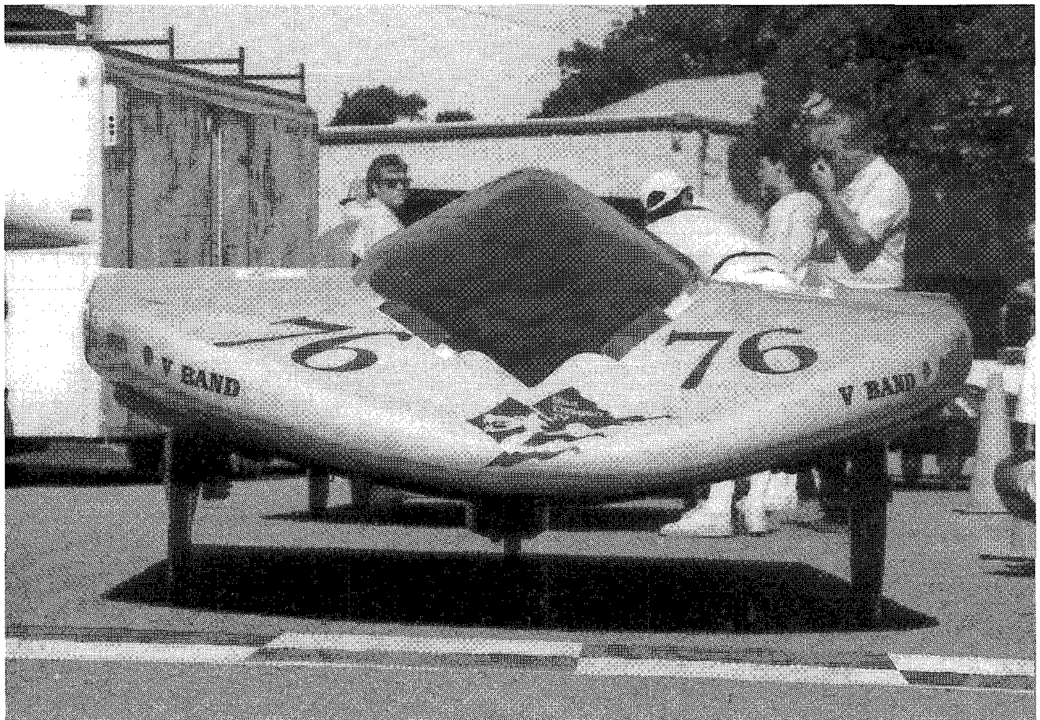
Batteries: Johnson Controls (Sears), 8 batteries, 96 volts, 4.98 kWh, 52 ah, 116 kg (256 lb).
Solar Cells: Semens Monocrystalline Silicon, 722 cells, 15% single cell rated efficiency, 1100 watts peak. 3 parallel modules. No peak power trackers.

Type of Solar Panel: Fixed flat panel.
Panel Voltage: 100 volts

Notes and Reported Problems During the Race: No power, low batteries from day 1 to 5 (never higher than 30% for five days). Practiced 2 days before race.



16th Place - Mankato State University



17th Place - Drexel University

Daily Average Speed kph(mph)
1 31.73(19.72)
2 20,79(12.92)
3 29.53(18.35)
4 17.09(10.62)
5 12.81(7.96)
6 32.16(19.99)
7 38.02(23.63)

Weight w/o Driver: 324 kg (714 lbs)
Length: 4.3 m (14.12 ft)
Width: 1.85 m (6.07 ft)
Height: 1 m (3.3 ft)
Wheelbase: 2.8 m (9.19 ft)
Track Width: 1.2 m (3.94 ft)
Clearance: .25 m (.82 ft)

Wheels and Tires: 48 spoke 66 cm (26 in) front wheels, 48 spoke 51 cm (20 in) back wheels. Avocet 4 x 51 cm (1.75 x 20 in) & 5 x 66 cm (1.9 x 26 in) tires @ 85 psi
Number of Wheels: 4
Est. Tire Rolling Resistance Coefficient: 0.0050/0.0055
Number of Flat Tires During the Race: 0

Brakes, Suspension, and Steering: Airhart hydraulic disk brakes,front. Mechanical/hydraulic disks on rear. Independent dual A arms with Koni mini sprint dirt track coil over shocks in front. Dual trailing arm rear, with coil over shocks. Bell crank steering.
Chassis: 4130 Chrome Moly 2.5 cm (1 in) OD x .124 cm (.049 in) wall, space frame. E glass/Epoxy/Nomex core body.
Motor: Solectria 8kw rated, 15 kW max, 6000 RPM, 96 volts, 11.8 kg (26 lb), 93% efficient at operating power level, 95% peak efficiency. Blower cooling.
Controls and Instrumentation: Solectria 98 motor controller. On board display of voltages, currents, temperatures, speed, no telemetry.
Transmission: Direct drive to rear wheel, #35-3/8: pitch chain, go cart sprockets.

Batteries: GNB, 16 batteries, 96 volts, 4.992 kWh, 52 ah, 109 kg (240 lb)
Solar Cells: Siemens, Monocrystalline Silicon, 738 cells, 13% single cell rated efficiency, 1000 watts peak. 4 flat facets. 4 Solectria peak power trackers. 47 kph (29 mph) on 1000 watts of power input to motor.

Type of Solar Panel: Fixed panel, two on sides, one on top and one on back. Cockpit centered in vehicle.
Panel Voltage: 75 volts

Notes and Reported Problems During the Race: Power tracker shut down back array on day 1, undetected until evening, causing depleted batteries on succeeding days. Wheel bearing failure

16th Place

Car: #3–Mankato State University. "Northern Light II". Automotive Eng. Tech., MSU Box 48, Mankato, MN 56002-8400 (507) 389-6383, FAX (507) 389-1095
Time: 79.88 hrs
Avg. Speed: 22.35 kph (13.89 mph)
Penalties: 22.187 hrs.
Days Finished Before 6:30 p.m.: 3
Total Distance: 1262 km (784.2 mi)
Country: USA

Team Captain: Ted Martin.
Faculty Advisor: Dr. Bruce Jones
Team Members: Dan Tinklenberg, Chris Harvey, Luke Matthies, Ryan Minnig, Scott Goblirsch, Kevin Schatz, Brian Byrnes, Kerry Andrews, Bob Dehncke, Mike Colon, Jamie Johnson, Bruce Anderson, Bobbi Sariin, Jamie Larson, Paul Willette, Troy Lawrence, Brian Lawrence, Jason Malisheske, Chris Lawson, Mark Karges, Eric Shubert.
Cost: $40,000
Project Time: 1 1/2 years.

Drag Coefficient, Cd: 0.22
Frontal Area A: 0.96 m^2 (7.13 ft^2)
Drag Area CdA: 0.21 m^2 (2.27 ft^2) 1/10 scale wind tunnel model.

Qualifying Speed: 78.0 kph (48.5 mph), 4th
Avg. Race Speed: 22.4 kph (13.9 mph)
Best Daily Avg. Speed: 38.0 kph (23.6 mph)
Slowest Daily Avg. Speed: 12.8 kph (8.0 mph)

day 1. Completely student built. Very simple 2 D body design, easy to construct. Practiced 1448 km (900 mi) before race.

17th Place

Car: #76—Drexel University. "Sun Dragon". 32nd & Chestnut Streets, Philadelphia, PA 19104 (215) 895-1351, FAX (215) 895-1695
Time: 81.07 hrs
Avg. Speed: 22.03 kph (13.69 mph)
Penalties: 27.47 hrs.
Days Finished Before 6:30 p.m.: 3
Total Distance: 1395.2 km (867.0 mi)
Country: USA

Team Captain: Paul Ciccone
Faculty Advisor: Dr. Michel Barsoum
Team Members: Erin Miller, David Slingbaum, Pablo Corbella, Todd Grintz, Frank Shillingford.
Cost: $75,000
Project Time: 9 mos.

Drag Coefficient, Cd: 0.15
Frontal Area A: 1 m^2 (10.8 ft^2)
Drag Area CdA: 0.15 m^2 (1.6 ft^2) Estimated from power vs. speed curves and coast down tests.

Qualifying Speed: 79.8 kph (49.6 mph), 2nd
Avg. Race Speed: 22.0 kph (13.7 mph)
Best Daily Avg. Speed: 29.9 mph, 48.1 kph
Slowest Daily Avg. Speed: 15.6 kph (9.7 mph)
Daily Average Speed kph(mph)
1 23.67(14.71)
2 22.86(14.21)
3 17.23(10.71)
4 18.84(11.71)
5 15.66(9.73)
6 42.74(26.56)
7 48.09(29.89)

Weight w/o Driver: 275 kg (607 lb)
Length: 5.9 m (19.36 ft)
Width: 2 m (6.6 ft)
Height: 1 m (3.3 ft)
Wheelbase: 2.4 m (7.87 ft)
Track Width: 1.5 m (4.92 ft)
Clearance: 0.25 m (0.82 ft)

Wheels and Tires: 48 spoke, 66 cm (26 in) wheels with spoke covers; Avocet 66 x 4 cm (26 x 1.5 in) Fat Boy slicks @ 110 psi
Number of Wheels: 3
Est. Tire Rolling Resistance Coefficient: 0.0050
Number of Flat Tires During the Race 2

Brakes, Suspension, and Steering: Hydraulic go-cart disk brakes all wheels. Regenerative Brakes. Double A arm, front, trailing arm rear, with nitrogen charged spring/dampers. Custom chain drive and tie rod steering.
Chassis: Carbon/Nomex beam frame, carbon skin.
Motor: Uniq Mobility DC brushless, 7.5 kW rated, 15 kW max, 5500 RPM, 100 volts, 4 kg (8.8 lb), 88 to 90% efficient at operating power level (actual dynamometer test), 92% peak efficiency. Blower cooling.
Controls and Instrumentation: Constant power/constant speed motor controller. 12 channel telemetry of voltages, currents, temperatures, speed to chase van.
Transmission: Direct drive cog belt to rear wheel, rated 97 - 98% efficient.

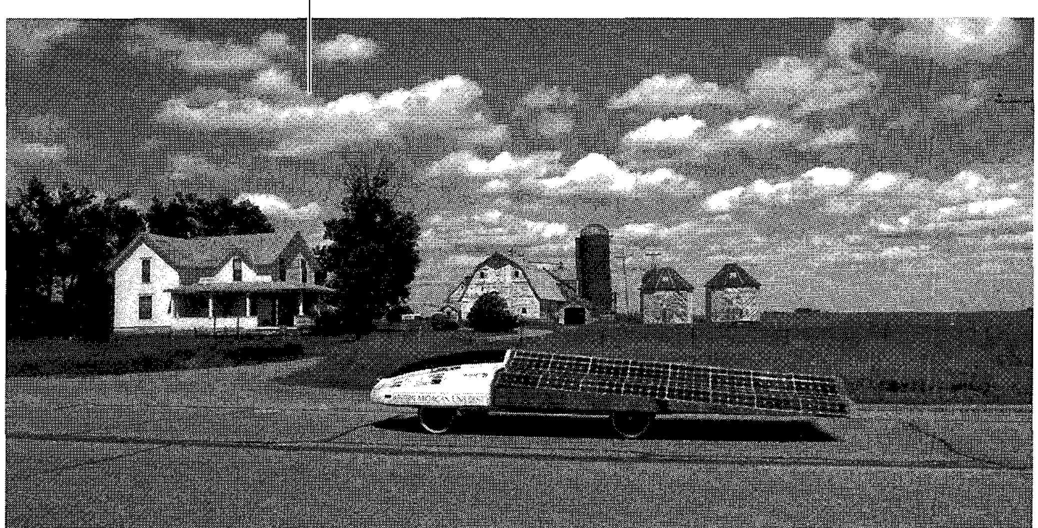
Batteries: Exide, 8 batteries, 96 volts, 4.7 kWh, 47 ah, 104 kg (230 lb).
Solar Cells: BP Monocrystalline Silicon, 800 cells, 87% areal packing, 17% single cell rated efficiency. 3 parallel strings. 3 AERL peak power trackers.

Type of Solar Panel: Fixed flat panel.
Panel Voltage: 156 volts open circuit.

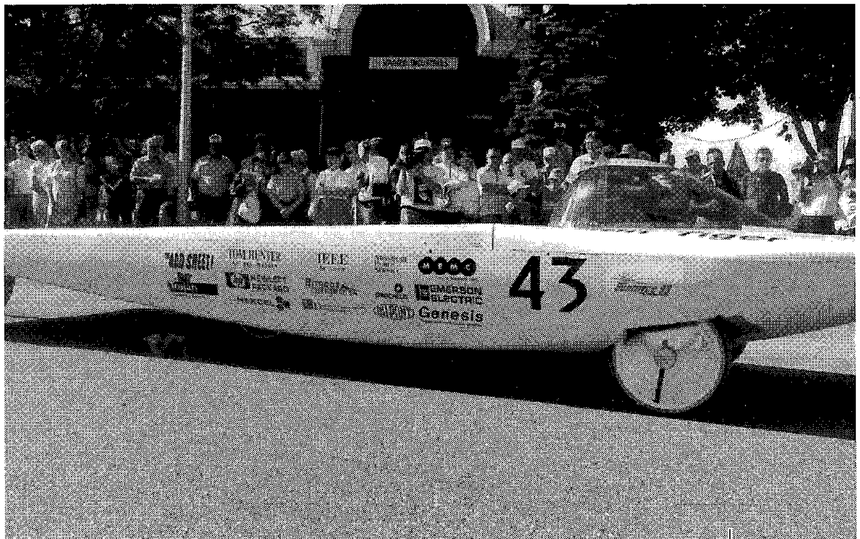
Notes and Reported Problems During the Race: Battery cell shorted, drained batteries. Had to replace batteries second day. Regenerative brake nonfunctional. Practiced 1569 km (975 mi) before race.

18th Place

Car: #93—Western Michigan University. "Sunseeker 93". Dept. of Mech/Aero Eng., Kalamazoo, MI 49008-5065 (616) 387-3366, FAX (616) 387-4024
Time: 81.16 hrs
Avg. Speed: 22.00 kph (13.67 mph)
Penalties: 23.237 hrs.
Days Finished Before 6:30 p.m.: 3



18th Place - Western Michigan University



19th Place - University of Missouri-Columbia

Total Distance: 1226.6 km (762.2 mi)
Country: USA

Team Captain: Mark Ely
Faculty Advisor: Richard C. Schubert, Richard Hathaway
Team Members: Mike Stavropoulos, Rob Sherwood, Rob Cavanagh, Dean Notter, Bart Cann, Kim Arnold, Bob Barta, Jim Blackwell, Dan Dangremond, Russ Ferguson, Ken Gross, Jon Knorr, Usman Mangla, Kevin Marsh, George Marutz, Jim Mazak, Erik Peterson, Jan Selesky, John St. Pierre, Mike Steffler, Mark Welch
Cost: $300,000
Project Time: 2 years

Drag Coefficient, Cd: 0.135
Frontal Area A: 1.07 m² (11.56 ft²)
Drag Area CdA: 0.145 m² (1.566 ft²) Computer solution VS Aero, from EDS.

Qualifying Speed: 36.5 kph (22.7 mph), 26th
Avg. Race Speed: 22.0 kph (13.7 mph)
Best Daily Avg. Speed: 38.6 kph (24.0 mph)
Slowest Daily Avg. Speed: 14.2 kph (8.8 mph)
Daily Average Speed kph(mph)
1 33.40(20.76)
2 19.74(12.27)
3 24.55(15.26)
4 16.49(10.25)
5 14.18(8.81)
6 30.99(19.26)
7 38.63(24.01)

Weight w/o Driver: 340 kg (750 lb)
Length: 6 m (19.69 ft)
Width: 2 m (6.6 ft)
Height: 1 m (3.3)
Wheelbase: 2.3 m (7.6 ft)
Track Width: 1.5 m (4.9 ft)
Clearance: 0.23 m (0.75 ft)

Wheels and Tires: 48 spoke, 51 cm (20 in) wheels with spoke covers; Avocet 51 x 4 cm (20 x 1.75 in) slick tires @ 100 psi
Number of Wheels: 4
Est. Tire Rolling Resistance Coefficient: 0.0055
Number of Flat Tires During the Race: 2

Brakes, Suspension, and Steering: Pro Stop hydraulic disk brakes front and rear. Independent hydraulic emergency brakes front & rear. Unequal length aluminum A arms front and rear, coil over shocks. Rack and Pinion steering manufactured by Strange Engineering. Adjustable air spring damper system.
Chassis: 6061-T6 Aluminum tubing space frame, 2.95 cm (1.16 in) OD, 0.147 cm (0.058 in) wall. Kevlar, foam cored rib body. Carbon fiber reinforced array structure.
Motor: Uniq Mobility DC brushless, 7.5 kW rated, 15 kW max, 10,000 RPM, 144 volts, 4.5 kg (9.9 lb), 85% efficient at operating power level. Forced air blower cooling.
Controls and Instrumentation: Telemetry of voltages, currents, temperatures; speed electronically displayed and chase vehicle monitored. Microprocessor controlled data acquisition system. Driver uses HP 95 LX microcomputer to scroll desired operating data for cockpit display (Battery & motor volts, amps, motor ROM, ground speed, temp of motor/controller & battery).
Transmission: Continuously variable transmission, with chain drive to rear differential for two wheel drive, allowing motor RPM's to remain between 4500 to 6200 RPM. (Manufacturer: Speed Selector).

Batteries: GNB,12 batteries, 144 volts, 4.8 kWh, 33 ah, 108 kg (238 lb).
Solar Cells: Two types of cells. BP Monocrystalline Silicon, 800 cells, 15% single cell rated efficiency, and Kyocera Poly crystalline silicone, 300 cells, 12% rated efficiency. 4 strings. 1200 watts peak power. Every 10 cells can be removed as a unit and replaced rapidly (velcro). 8 Solectria peak power trackers.

Type of Solar Panel: Fixed panel with a eight flat facets.
Panel Voltage: 144 volts

Notes and Reported Problems During the Race: Wrong gear first day, stalled on hill. Array shorting against carbon conductive array support causing severe loss in array power output. Continual array wiring problems. Low battery 2nd through 4th day. Data acquisition and telemetry was unreliable. Practiced 2 days before race.

19th Place

Car: #43—University of Missouri-Columbia. "SunTiger". 349 Engineering Building West, Columbia, MO 65211 (314) 882-3242, FAX (314) 882-0397

Time: 82.95 hrs
Avg. Speed: 21.52 kph (13.37 mph)
Penalties: 24.856 hrs.
Days Finished Before 6:30 p.m.: 2
Total Distance: 1228.3 km (763.3 mi)
Country: USA
Team Captains: Tim Mattingly, Jon Northup
Faculty Advisors: Dr. Richard Wallace, Rick Whelove
Team Members: Kevin Hein, Tim Hall, Nick Hennen, Chris Gibiser, Martin Heinrich, Rick Ellsworth, Derek Sharpe, Mike Kuehnel, Scott Schunk, Doug Calhoun, James Pyland, Kevin Yoon, John Ferrell, Rex Gish, Lynn Ohman
Cost: $51,000
Project Time: 2 years

Qualifying Speed: 69.5 kph (43.2 mph), 8th
Avg. Race Speed: 21.5 kph (13.4 mph)
Best Daily Avg. Speed: 32.8 kph (20.4 mph)
Slowest Daily Avg. Speed: 16.9 kph (10.5 mph)
Daily Average Speed kph(mph)
1 30.80(19.14)
2 20.90(12.99)
3 16.85(10.47)
4 18.95(11.78)
5 17.51(10.88)
6 28.06(17.44)
7 32.78(20.37)

Weight w/o Driver: 427 kg (941 lbs)
Length: 6 m (19.7 ft)
Width: 2 m (6.6 ft)
Height: 1 m (3.3 ft)
Wheelbase: 1.6 m (5.3 ft)
Track Width: 1.5 m (4.9 ft)
Clearance: 0.2 m (0.66 ft)

Wheels and Tires: 48 spoke, 51 cm (20 in) wheels with spoke covers; Avocet Freestyle 51 x 4 cm (20 x 1.75 in) city slick tires @ 120 psi
Number of Wheels: 4 (with 2 narrowly spaced in rear).
Est. Tire Rolling Resistance Coefficient: 0.0055
Number of Flat Tires During the Race: 0

Brakes, Suspension, and Steering: Hydraulic disk brakes front and back. Regenerative Brakes. Unequal non parallel A arms front, rear trailing link, oil damped coil over shocks. Rack and Pinion steering, push/pull cable to tie rods.
Chassis: Frame—carbon reinforced foam core beams. Body—carbon/Nomex honeycomb.
Motor: Solectria DC brushless, 6 kW rated, 12 kW max, 6000 RPM, 96 volts, 60 amps, 11.8 kg (26 lb), 88% efficient at operating power level, 94% peak efficiency.
Controls and Instrumentation: Cockpit display of speed, voltage, amps, temperature. Constant speed controller. No telemetry.
Transmission: Direct chain drive 6/1 ratio.

Batteries: Gates Genesis, 16 batteries, 96 volts, 4.99 kWh, 52 ah, 159 kg (350 lb).
Battery Charge Each Day, Percent at Start/Finish:
1 100%/10%
2 20/5%
3 25/0%
4 40/10%.
5 35/0%
6 25/0%
7 20/15%
Solar Cells: Astro Power solar cells, Monocrystalline Silicon, 760 cells, 14.2% single cell rated efficiency, 12.5% measured efficiency, 950 watts peak. 2 strings. 2 AERL peak power trackers.

Type of Solar Panel: Fixed flat panel.
Panel Voltage: 120 volts
Reported Maximum Instantaneous Panel Power During Race: 1035 W
Reported Panel Power on a Sunny Day at High Noon: 840 W
Reported Average Panel Power From 8 a.m. to 5 p.m. During a Sunny Day: 650 W
Reported Speed on 750 Watts of Panel Power: 48 kph (30 mph)

Notes and Reported Problems During the Race: Instrumentation failed. Low battery, changed 1/2 of batteries on Day 6. Motor/controller overheated. Installed temporary fan on controller. Rear brake dragged. Practiced 97 km (60 mi) before the race.

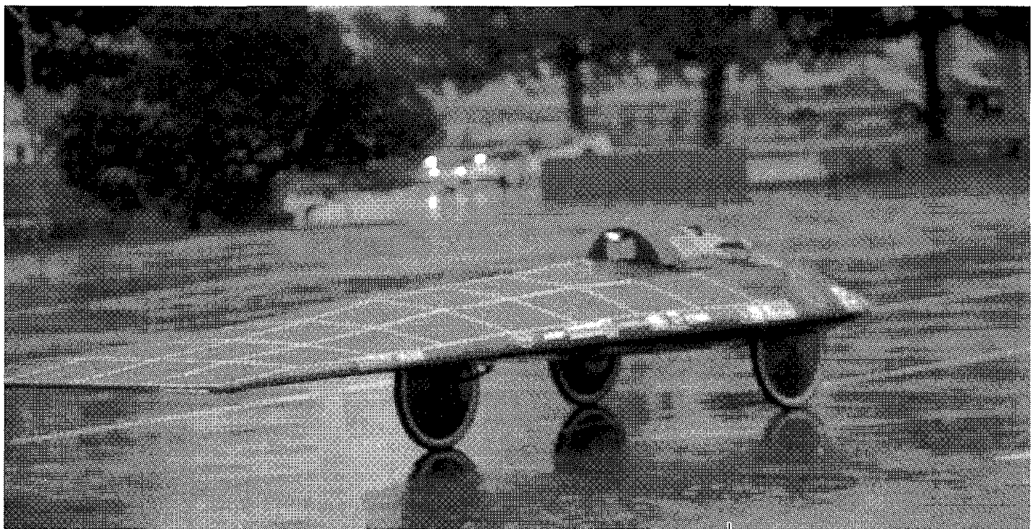
20th Place

Car: #6—Virginia Polytechnic Institute. "Solaray II". Mechanical Engineering Dept., Blacksburg, VA 24061-0238 (703) 231-7190, FAX (703) 231-9100
Time: 85.24 hrs
Avg. Speed: 20.95 kph (13.02 mph)
Penalties: 29.387 hrs.
Days Finished Before 6:30 p.m.: 3
Total Distance: 1088.2 km (676.2 mi)
Country: USA

Team Captain: John Cochoy
Faculty Advisor: Dr. Charles J. Hurst
Team Members: Fred Hammerle, Jeff May, Andrew Doan, Tracey Grube, Kevin Coogan, Rob Demaree, Dimos Katsis, Mark Ruslin
Cost: $70,000
Project Time: 1 1/2 years

Drag Coefficient, Cd: 0.14
Frontal Area A: 1 m^2 (10.8 ft^2)
Drag Area CdA: 0.14 m^2 (1.5 ft^2)
1/12 scale wind tunnel model.

Qualifying Speed: 79.7 kph (49.5 mph), 3rd
Avg. Race Speed: 20.9 kph (13.02 mph)



20th Place - Virginia Polytechnic University

Best Daily Avg. Speed: 39.8 kph (24.7 mph)
Slowest Daily Avg. Speed: 13.0 kph (8.1 mph)
Daily Average Speed kph(mph)

1 32.29(20.07)
2 18.37(11.42)
3 23.31(14.49)
4 14.71(9.14)
5 12.97(8.06)
6 37.06(23.03)
7 39.69(24.67)

Weight w/o Driver: 360 kg (794 lbs)
Length: 6 m (19.7 ft)
Width: 2 m (6.6 ft)
Height: 1 m (3.3 ft)
Wheelbase: 2.4 m (7.9 ft)
Track Width: 1.3 m (4.3 ft)
Clearance: 0.25 m (0.82 ft)

Wheels and Tires: 48 spoke, 66 cm (26 in) wheels with spoke covers; Avocet 66 x 4.8 cm (26 x 1.9 in) slick tires @ 80 psi
Number of Wheels: 3
Est. Tire Rolling Resistance Coefficient: 0.0050
Number of Flat Tires During the Race: 1

Brakes, Suspension, and Steering: Enginetics hydraulic disk brakes on three wheels, duel master cylinders. Regenerative brake. Double unequal A arm front, trailing arm rear. Racing Genesis air shocks. Cable/cross bar steering.
Chassis: Aluminum box frame, riveted and glued. Carbon/foam body.
Motor: Student designed, Motion Control, DC brush motor, 11.9 kW rated, 3000 RPM, 144 volts, 11.8 kg (26 lb), 85% efficient at operating power level, 90% peak efficiency (dynamometer tested).
Controls and Instrumentation: Motion Control System motor controller. Telemetry to chase van of buss voltage, battery current, battery ampere hours, array current, speed, and odometer.
Transmission: Direct drive single reduction cog belt.

Batteries: Concord gel cell battery, 12 batteries, 144 volts, 5 kWh, 34 ah, 127 kg (280 lb).
Solar Cells: AstroPower solar cells, Monocrystalline Silicon, 720 cells, 13.9% single cell rated efficiency, 4 strings. 4 Solectria peak power trackers. 650 watts maximum array output. 55 kph (34 mph) on 1000 watts of input to motor.

Type of Solar Panel: Fixed, single surface gently curved panel
Panel Voltage: 80 volts

Notes and Reported Problems During the Race: Day 2—motor controller failed, loose wire. Low battery Day 2 through Day 5. Practiced 965 km (600 mi) before race.

21st Place

Car: #35 - University of Minnesota. "Aurora". 111 Church Street, SE, Room 142, Mech. Eng., Minneapolis, MN 55455 (612) 625-3441, FAX (612) 625-6069
Time: 85.29 hrs
Avg. Speed: 20.94 kph (13.01 mph)
Penalties: 26.7997 hrs.
Days Finished Before 6:30 p.m.: 3
Total Distance: 1169 km (726.4 mi)
Country: USA

Team Captains: John Anderson, Scott Grabow, Brad Schultz, Matt KirkWood, Tim Timmerman.
Faculty Advisors: Dr. Patrick Starr, Dr. Virgil Marple
Team Members: Rob Miller
Cost: $150,000
Project Time: 2 1/2 years

Drag Coefficient, Cd: 0.18
Frontal Area A: 1.57 m^2 (16.96 ft^2)
Drag Area CdA: 0.28 m^2 (3.02 ft^2) 1/4 scale wind tunnel model

Qualifying Speed: 53.9 kph (33.5 mph), 12th
Avg. Race Speed: 13.0 mph, 20.9 kph
Best Daily Avg. Speed: 37.8 kph (23.5 mph)
Slowest Daily Avg. Speed: 14.8 kph (9.2 mph)
Daily Average Speed kph(mph)

1 30.46(18.93)
2 20.79(12.92)
3 17.20(10.69)
4 17.52(10.89)
5 14.82(9.21)

6 30.15(18.74)
7 37.87(23.54)

Weight w/o Driver: 377 kg (831 lb)
Length: 5.94 m (19.49 ft)
Width: 1.98 m (6.5 ft)
Height: 1.5 m (4.9 ft)
Wheelbase: 2.4 m (7.9 ft)
Track Width: 1.8 m (5.9 ft)
Clearance: 0.15 m (0.49 ft)

Wheels and Tires: 48 spoke, 66 cm (26 in) wheels with spoke covers; Avocet Fasgrip City 66 x 4.8 cm (26 x 1.9 in) slick tires @ 85 psi
Number of Wheels: 4
Est. Tire Rolling Resistance Coefficient: 0.0050
Number of Flat Tires During the Race: 0

Brakes, Suspension, and Steering: Polaris hydraulic disk brakes—3 wheels, 7075 aluminum disks, titanium coated. Regenerative Brake. Double trailing arms, front, with coil over shocks. Rear trailing arms, with coil over shocks. Rack and Pinion steering.
Chassis: Carbon/monocoque frame. Carbon/Nomex body and panel.
Motor: Solectria BRLSH DC brushless, 7.5 kW rated, 15 kW max, 6000 RPM, 96 volts, 21.7 kg (47.8 lb), 90% efficient at operating power level, 94% peak efficiency.
Controls and Instrumentation: Buss voltage, panel battery and motor currents, speed distance and motor RPM displayed
Transmission: Parallel/series motor switch gives 2/1 speed reduction. Double reduction cog belt to motor, 3/8 inch pitch chain to rear wheel. Fixed gears.

Batteries: GNB, 8 batteries, 96 volts, 3.8 kWh, 40 ah, 80 kg (176 lb).
Battery Charge Each Day, Percent at Start/Finish
1 100%/13%
2 38/29%
3 53/?%
4 75/?%.
5 65/0%
6 90/?%
7 84/?%
Solar Cells: Siemens, Monocrystalline Silicon, 1672 cells, 15% single cell rated efficiency, 13% overall panel efficiency, 1290 watts peak. 5 facets top and sides. 5 Solectria peak power trackers.

Type of Solar Panel: Fixed panel with a 5 flat or gently warped facets.
Panel Voltage: 96 volts
Reported Maximum Instantaneous Panel Power During Race: 1290 W
Reported Panel Power on a Sunny Day at High Noon: 870 W
Reported Average Panel Power From 8 a.m. to 5 p.m. During a Sunny Day: 570 W
Reported Speed on 630 Watts of Panel Power: 55 kph (34 mph)

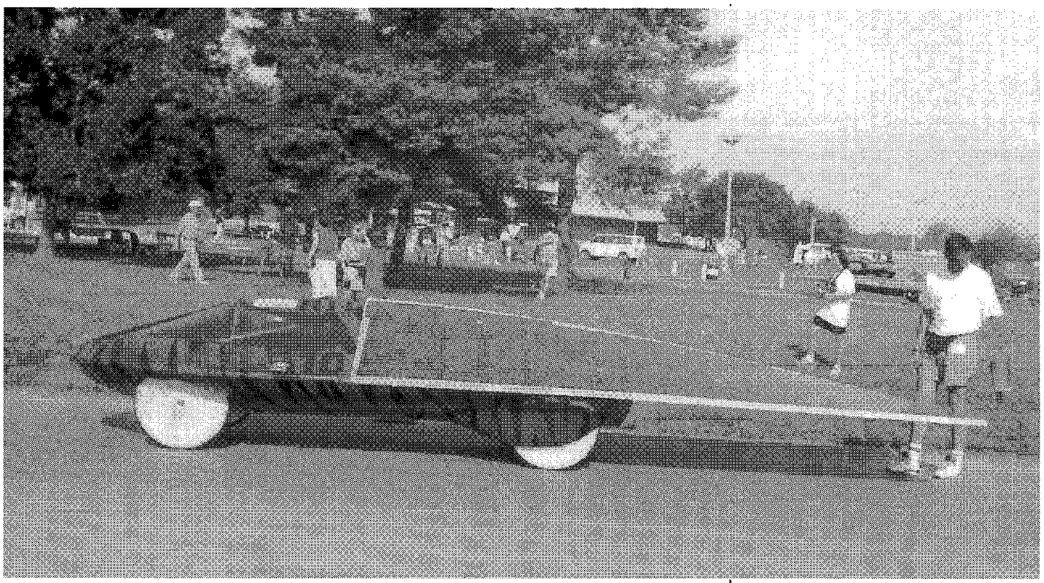
Notes and Reported Problems During the Race: The solar cells were covered with a transparent coating. When tested, 20% of the radiative energy was lost when the sunlight was not perpendicular to the cell. When the sun was normal, the coating caused no apparent loss. Had one bad cell which caused a power loss in the left upper array, the cell was bypassed permanently during the race. On day 5, the batteries were charging unevenly (4 batteries were at 12v, 2 at 10v, 1 at 8v and 1 at 6v). The two low batteries were replaced, charged up to buss voltage independently, and then charged with the pack. Two broken spokes on day 1. Practiced 483 km (300 mi) before the race.

22nd Place

Car: #10—Rochester Institute of Technology. "Spirit". Mech. Eng., One Lomb Memorial Drive, Rochester, NY 14623 (716) 475-6121, FAX (716) 475-6879
Time: 85.76 hrs
Avg. Speed: 20.82 kph (12.94 mph)
Penalties: 26.487 hours
Days Finished Before 6:30 p.m.: 1
Total Distance: 1170.2 km (727.2 mi)
Country: USA

Team Captain: Geoffrey Hitchings
Faculty Advisor: Dr. Alan H. Nye
Team Members: Chris Kelley, Jeff Szczepanski, Jake McKernan, Dave Hartman, Edward Avila, Jacob Allison, Paul Myers, Dave

21st Place - University of Minnesota



22nd Place - Rochester Institute of Technology

Butler, Jeff Haines, David Kavanagh, Kevin Kerr, Bill Keiser, Heather Lent, Deana Mallo, Kenneth Shopland, Guy Vottis.
Cost: $100,000
Project Time: 1 1/2 years.

Drag Coefficient, Cd: 0.25
Frontal Area A: 1.1 m² (11.9 ft²)
Drag Area CdA: 0.275 m² (2.97 ft²) Estimate only, not measured.

Qualifying Speed: 55.6 kph (34.6 mph), 18th
Avg. Race Speed: 20.8 kph (12.9 mph)
Best Daily Avg. Speed: 31.9 kph (19.8 mph)
Slowest Daily Avg. Speed: 14.0 kph (8.7 mph)
Daily Average Speed kph(mph)
1 27.82(17.29)
2 20.18(12.54)
3 24.55(15.26)
4 16.64(10.34)
5 14.01(8.71)
6 24.25(15.07)
7 31.84(19.81)

Weight w/o Driver: 283 kg (624 lb)
Length: 6 m (19.7 ft)
Width: 2 m (6.6 ft)
Height: 1 m (3.3 ft)
Wheelbase: 2.36 m (7.74 ft)
Track Width: 1.2 m (3.9 ft)
Clearance: 0.25 m (0.82 ft)

Wheels and Tires: 48 spoke, 61 cm (24 in) wheels with spoke covers; Panaracer 61 x 3 cm (24 x 1.25 in) slick tires @ 100 psi
Number of Wheels: 4
Est. Tire Rolling Resistance Coefficient: 0.0050
Number of Flat Tires During the Race: 2

Brakes, Suspension, and Steering: Hydraulic disk brakes 2 front and one rear (3), emergency brake, rear wheel. Double A arm front, with Pensky coil over shocks. Trailing arm rear, with coil over shocks. Rack and Pinion steering.
Chassis: 6061-T6 Aluminum tubing space frame, 3.8 cm (1.5 in) OD, 0.10 cm (0.040 in) wall. Fiberglass/ Nomex body.
Motor: GE DC brushless, 3.7 kW rated 7000 RPM, 150 volts, 7.7 kg (17 lb), 92% efficient at operating power level, 93% peak efficiency. Blower cooling.
Controls and Instrumentation: GE motor controller. Telemetry of voltages, currents, temperatures, cab temperature, to chase van.
Transmission: Direct drive #35, 0.95 cm (3/8 in) pitch motor cycle chain to rear wheel.

Batteries: Yuasa, 13 batteries, 156 volts, 4.8 kWh, 24 ah, 141 kg (310 lb).
Solar Cells: BP Solar Cells, Monocrystalline Silicon, 4258 cells, 17% single cell rated efficiency, 1000 watts peak. 10 strings. 9 AERL peak power trackers. 56 kph (35 mph) on 1000 watts of input to the motor.

Type of Solar Panel: Fixed panel with a two gently warped facets.
Panel Voltage: 156 volts

Notes and Reported Problems During the Race: Array put out about 450 watts max instead of 1000 watts. The problem was due to broken electrical connections between cells, the encapsulant may have shorted to the frame, and the peak power trackers may have been damaged. Practiced 563 km (350 mi) before the race.

23rd Place

Car: #222—Stark Technical College. "Solar Clipper". 6200 Frank Ave., NW Canton, OH 44720 (216) 494-6170, FAX (216) 494-6313
Time: 86.03 hrs
Avg. Speed: 20.76 kph (12.90 mph)
Penalties: 27.187 hrs
Days Finished Before 6:30 p.m.: 2
Total Distance: 1145.3 km (711.7 mi)
Country: USA

Team Captains: Annette LaFromboise, Chris Boyer, Jim Russ
Faculty Advisors : Karl Tonhaeuser, Vern Sproat
Team Members: Scott Klemens, Andy de LaGrange
Cost: $250,000
Project Time: 2 1/2 years.

Drag Coefficient, Cd: 0.23
Frontal Area A: 1.7 m^2 (15.12 ft^2)
Drag Area CdA: 0.39 m^2 (4.21 ft^2) Estimated from calculations.

Qualifying Speed: 69.8 kph (43.4 mph), 7th
Avg. Race Speed: 20.8 kph (12.9 mph)
Best Daily Avg. Speed: 45.4 kph (28.2 mph)
Slowest Daily Avg. Speed: 17.4 kph (10.8 mph)
Daily Average Speed kph(mph)
1 28.41(17.66)
2 14.43(8.97)
3 26.36(16.38)
4 17.41(10.82)
5 17.91(11.13)
6 7.95(12.80)
7 45.41(28.22)
Weight w/o driver: 419 kg (923 lbs)
Length: 6 m (19.7 ft)
Width: 1.94 m (6.37 ft)
Height: 1.27 m (4.17 ft)
Wheelbase: 2.9 m (9.5 ft)
Track Width: 1.3 m (4.27 ft)
Clearance: 0.25 m (0.82 ft)

Wheels and Tires: 48 spoke, 66 cm (26 in) wheels with spoke covers; Avocet 66 x 5 cm (26 x 1.95 in) slick tires @ 80 psi
Number of Wheels: 4
Est. Tire Rolling Resistance Coefficient: 0.0055

Brakes, Suspension, and Steering: Hydraulic Suzuki motor cycle disk brakes front and one rear, regenerative brake. MacPherson strut, with Yamaha spring over shocks in front, trailing arm rear, with gas spring/shocks. Link and tie rod steering.
Chassis: 6061-T6 Aluminum tubing space frame, 3.8 cm (1.5 in) OD. Kevlar/fiberglass body.
Motor: Uniq DC brushless, 7.5 kW rated, 15 kW max, 5000 RPM, 100 volts, 3.9 kg (8.6 lb), 90% efficient at operating power level, 94% peak efficiency. Blower cooling.
Controls and Instrumentation: Constant speed motor controller. Telemetry of voltages, currents, temperatures, to chase van.
Transmission: Direct drive chain to rear wheel.

Batteries: Powersonic, 16 batteries, 96 volts, 5.0 kWh, 52 ah, 135 kg (298 lb).
Solar Cells: BP Solar Saturn Cells, Monocrystalline Silicon, 900 full cells, 50 partial, 17% single cell rated efficiency, 15% actual, 1000 watts peak. 5 facets. 6 self designed and manufactured peak power trackers.
Type of Solar Panel: Fixed panel with a 5 flat facets.
Panel Voltage: 200 volts

Notes and Reported Problems During the Race: Low batteries day 2 to day 6. Rear vision color TV system built by students. Practiced 282 km (175 mi) before the race.

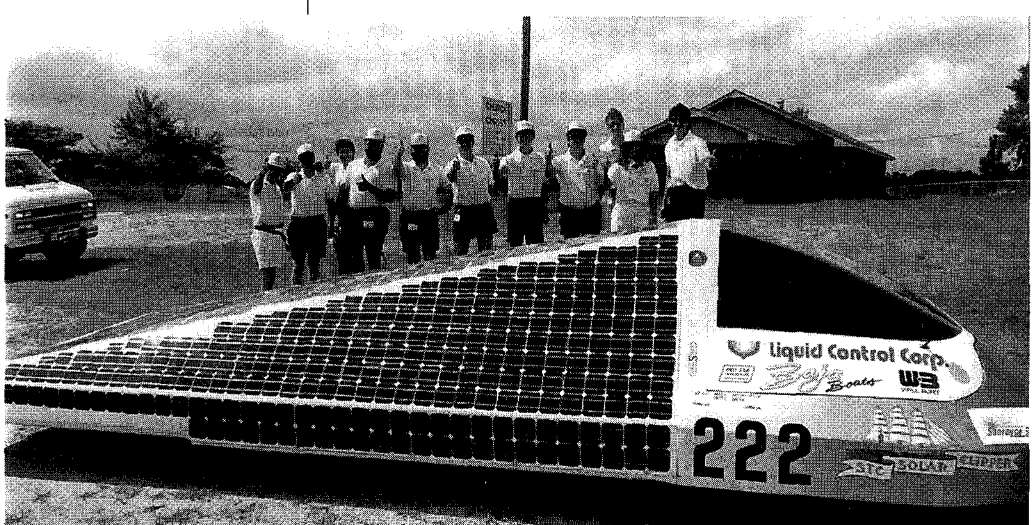
24th Place

Car: #32—Colorado State University. "Solar Ram". Dept. of Mech. Eng., Fort Collins, CO 80523 (303) 491-8617, FAX (303) 491-8544
Time: 87.03 hrs
Avg. Speed: 20.52 kph (12.75 mph)
Penalties: 28.537 hrs
Days Finished Before 6:30 p.m.: 2
Total Distance: 1114.8 km (692.7 mi)
Country: USA

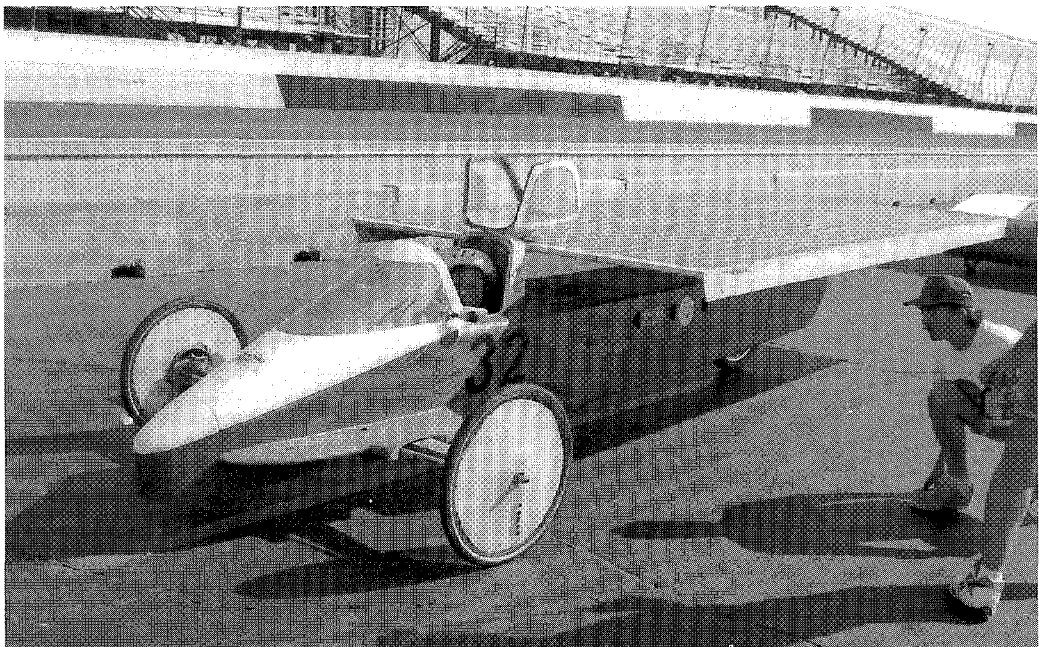
Team Captains: Brad Schuelz, Roger Ross, Brian Barber
Faculty Advisor: Dr. Douglas Hittle
Team members: Matt Miscio, Pat Hansen, Bryan Golding, Esten Daniels, Tom Doran
Cost: $80,000
Project Time: 1 1/2 years.

Drag Coefficient, Cd: 0.28
Frontal Area A: .75 m^2 (8.1 ft^2)
Drag Area CdA: 0.21 m^2 (2.27 ft^2) Estimate only.

Qualifying Speed: 61.9 kph (38.5 mph), 11th
Avg. Race Speed: 12.8 mph. 20.5 kph
Best Daily Avg. Speed: 45.0 kph (28.0 mph)
Slowest Daily Avg. Speed: 14.9 kph (9.3 mph)
Daily Average Speed kph(mph)
1 28.45(17.68)
2 18.49(11.49)



23rd Place - Stark Technical College



24th Place - Colorado State University

3 30.12 (18.72)
4 16.89 (10.50)
5 14.88 (9.25)
6 16.07 (9.99)
7 44.99 (27.96)

Weight w/o Driver: 315 kg (694 lb)
Length: 6 m (19.7 ft)
Width: 2 m (6.6 ft)
Height: 1.1 m (3.6 ft)
Wheelbase: 3.3 m (10.8 ft)
Track Width: 1.8 m (5.9 ft)
Clearance: 0.18 m (0.59 ft)

Wheels and Tires: 36 spoke, 66 cm (26 in) wheels with spoke covers; Specialized Fat Boy 66 x 4 cm (26 x 1.50 in) slick tires @ 80 psi
Number of Wheels: 3
Est. Tire Rolling Resistance Coefficient: 0.0050

Brakes, Suspension, and Steering: Custom front drum brake. Cable actuated mountain bike hydraulic disk in rear. Composite single flex beam suspension in front, rear composite trailing arm with coil over shock. Motor mounted to trailing arm. Rack and Pinion steering.
Chassis: Carbon/Kevlar/Nomex honeycomb monocoque body.
Motor: Uniq DC brushless, 7.5 kW rated, 15 kW max, 4000 RPM, 100 volts, 4.5 kg (9.9 lb), 90% efficient at operating power level. Blower cooling.
Controls and Instrumentation: Constant power/constant speed motor controller. No telemetry. Cockpit display of motor, battery, and panel voltages and currents.
Transmission: Direct cog belt drive.

Batteries: Optima, sealed gel cell, 7 batteries, 84 volts, 4.7 kWh, 56 ah, 127 kg (280 lb).
Solar Cells: Siemens solar cells, monocrystalline silicon, 741 cells, 14% single cell rated efficiency, overall panel efficiency 13%, 1000 watts peak. 4 series strings in parallel 4 Brusa peak power trackers.

Type of Solar Panel: Tilting flat panel with foldout panels underneath which can be extended for stationary charging in the evening.
Panel Voltage: 80 volts

Notes and Reported Problems During the Race: Shorted array connector, continual problems with array connections. Blower control failed. Low battery due to non-matched battery voltage. Changed bad battery. The car has a unique front suspension, a composite beam acts as both spring and damper. Extremely compact front wheel packaging. On board computer controls speed, power, array tracking, etc. Automatic tilting of panel with satellite star tracker and electric driven lead screw/control system to automatically optimize panel power vs. tilt angle. Practiced 97 km (60 mi) before the race.

25th Place

Car: #11—Auburn University. "Sol of Auburn". Dept. of Mech. Eng., 201 Ross Hall, Auburn, AL 36849-5341 (205) 844-3303, FAX (205) 844-3307
Time: 90.07 hrs
Avg. Speed: 19.83 kph (12.32 mph)
Penalties: 30.703 hrs
Days Finished Before 6:30 p.m.: 2
Total Distance: 1135.2 km (705.4 mi)
Country: USA

Team Captain: Brent Hart.
Faculty Advisor: Dr. Sushil Bhavnani
Team Members: Slater Voorhees, Steve Rose, Kit Cowan, Wendell Simmons, Ware Bedell, Kevin Redman, Morgan Simpson, David Stephens, James Stutts, Darin Dix, Christian Sanders, Joe Haggerty, Jason Woodworth, Kay Dudley, Mindi Morris.
Cost: $25,000
Project Time: 1 1/2 years.

Drag Coefficient, Cd: 0.14
Frontal Area A: 1.05 m^2 (11.34 ft^2)
Drag Area CdA: 0.147 m^2 (1.59 ft^2) 1/6 scale wind tunnel model.

Qualifying Speed: 71.3 kph (44.3 mph), 6th
Avg. Race Speed: 19.83 kph (12.32 mph)
Best Daily Avg. Speed: 33.6 kph (20.9 mph)

Slowest Daily Avg. Speed: 14.1 kph (8.8 mph)

Daily Average Speed kph(mph)

1 17.89(11.12)
2 24.65(15.32)
3 21.64(13.45)
4 16.35(10.16)
5 14.11(8.77)
6 24.60(15.29)
7 33.55(20.85)

Weight w/o Driver: 357 kg (786 lbs)
Length: 6 m (19.7 ft)
Width: 2 m (6.6 ft)
Height: 1.1 m (3.6 ft)
Wheelbase: 2.4 m (7.9 ft)
Track Width: 1.45 m (4.8 ft)
Clearance: 0.15 m (0.49 ft)

Wheels and Tires: 36 spoke, 51 cm (20 in) wheels with spoke covers; Avocet Fasgrip 51 x 4 cm (20 x 1.75 in slick tires @ 85 psi
Number of Wheels: 4
Est. Tire Rolling Resistance Coefficient: 0.0055
Number of Flat Tires During the Race: 0

Brakes, Suspension, and Steering: Front hydraulic disk, rear cable actuated mountain bike disc brakes. Double A arm with Risse Racing Technology mountain bike gas shocks all four wheels. Rear trailing arm. Rack and Pinion steering.
Chassis: Frame, carbon composite single box beam with Y extensions in rear. Kevlar honeycomb body.
Motor: Solectria DC brushless, 6kW rated, 6000 RPM, 96 volts, 11.8 kg (26 lb), 92% efficient at operating power level, 94% peak efficiency.
Controls and Instrumentation: Constant power/constant speed control. Digital readouts of amps, volts, temperatures, battery, array, motor, and controller, plus ampere hours of battery. Rear view from TV camera.
Transmission: Direct double reduction cog belt drive with 5/1 overall ratio.
Batteries: GNB Pulsar, 16 batteries, 96 volts, 4.9 kWh, 26 ah, 109 kg (240 lb)
Solar Cells: Astro Power solar cells, Monocrystalline Silicon, 2500 cells, 13.6% single cell rated efficiency, 700 watts peak. 9 strings. No peak power trackers.

Type of Solar Panel: Fixed panel with a five gently warped facets.
Panel Voltage: 126 volts
Reported Maximum Instantaneous Panel Power During Race: 700 W
Reported Panel Power on a Sunny Day at High Noon: 650 W
Reported Speed on 650 Watts of Panel Power: 40.2 kph (25 mph)

Notes and Reported Problems During the Race: Gambled on outrunning weather system on Day 1, didn't make it. Ran on low batteries Day 1 through Day 5. Bad weather for 5 days including lightening storm on Day 4. Overheated current sensors. Finite element analysis used to design a variable web height graphite I beam frame. Practiced 257 km (160 mi) before the race.

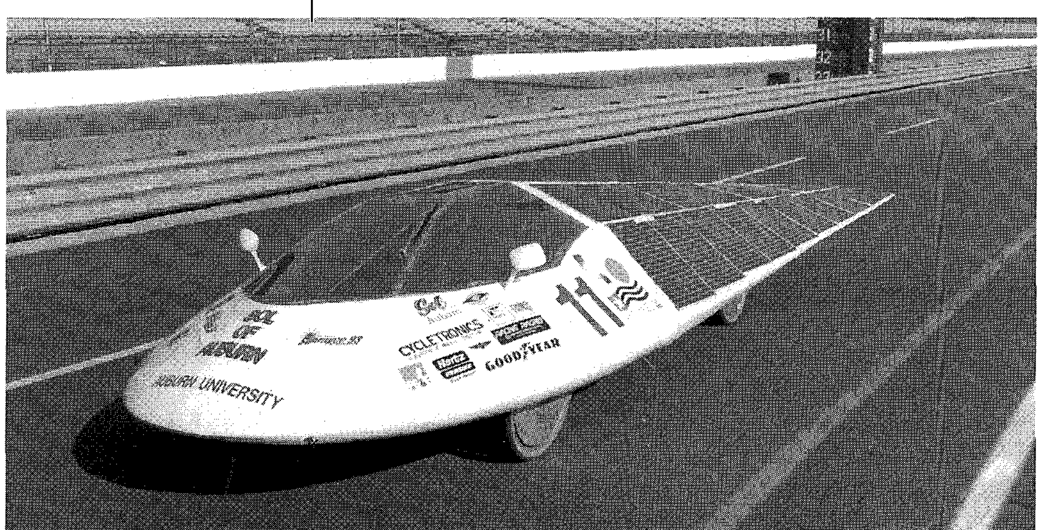
26th Place

Car: #125—University of Ottawa. "Team Ralos II". ESTco, 33 Mann Avenue, Ottawa, Ontario, Canada K1N 6N5 (613) 564-6818, FAX (613) 564-9842
Time: 90.32 hrs
Avg. Speed: 19.76 kph (12.28 mph)
Penalties: 31.10 hrs
Days Finished Before 6:30 p.m.: 1
Total Distance: 1100.8 km (684.0 mi)
Country: Canada

Team Captain: Philippe Gow
Faculty Advisors: Professor W. Adams, Professor R Milane
Team Members: Frank Neitzert, Gordan Cormier, Richard Briggs, Vivek Sarin
Cost: Can$150,000
Project Time: 2 years.

Drag Coefficient, Cd: 0.10
Frontal Area A: 1.7 m^2 (18.4 ft^2)
Drag Area CdA: 0.17 m^2 (1.84 ft^2) 1/8 scale NRC wind tunnel, plus BS Aero math modeling.

Qualifying Speed: 38.6 kph (24.0 mph), 31st
Avg. Race Speed: 19.8 kph (12.3 mph)
Best Daily Avg. Speed: 30.4 kph (18.9 mph)



25th Place - Auburn University

26th Place - University of Ottawa

Slowest Daily Avg. Speed: 15.3 kph (9.5 mph)
Daily Average Speed kph(mph):
1 22.19(13.79)
2 16.54(10.28)
3 22.12(13.75)
4 15.35(9.54)
5 15.99(9.94)
6 27.88(17.33)
7 30.46(18.93)

Weight w/o Driver: 340 kg (749 lb)
Length: 5.98 m (19.62 ft) **Width**: 2 m (6.6 ft)
Height: 1 m (3.3 ft) **Wheelbase**: 2.57 m (8.43 ft)
Track Width: 1.42 m (4.66 ft)
Clearance: 0.10 m (0.33 ft)

Wheels and Tires: Wheelchair 5 spoke 51 cm (20 in) aluminum wheels, modified, with spoke covers; Avocet 51 x 4.4 cm (20 x 1.75 in) slick tires @ 100 psi
Number of Wheels: 3
Est. Tire Rolling Resistance Coefficient: 0.0055
Number of Flat Tires During the Race: 1

Brakes, Suspension, and Steering: Enginetics hydraulic disk brakes on three wheels. Regenerative Brake. Unequal double A arm front suspension with aircraft Bungy adjustable springs. Motorcycle air dampers. Rear swing arm with motorcycle coil over shock. Rack and Pinion steering.
Chassis: 6061-T6 Aluminum tubing space frame, 1.9 to 6.4 cm (.75 to 2.5 in) diameter, 0.76-0.32 (0.030-0.125 in) wall. Foam/Kevlar/Carbon sandwich body.
Motor: Uniq DR086 DC brushless, 7.5 kW rated, 15 kW max, 3000 RPM, 84 volts, 100 Amps, 4.5 kg (9.9 lb).
Controls and Instrumentation: Constant speed motor controller. Cockpit display of speed, distance, motor, panel, and battery currents and voltages plus motor temperature.
Transmission: Two stage reduction, poly chain first stage, bicycle chain second stage. 7/1 to 12/1 reductions are available.

Batteries: Douglas 22 NF batteries, 7 batteries, 84 volts, 4.5 kWh, 54 ah, 98 kg (217 lb)
Solar Cells: ARCO **(Richard-Siemens?)** & Astro Power solar cells, Monocrystalline Silicon, 900 cells, 14% single cell rated efficiency, overall panel efficiency 13.5%, 900 watts peak. Three individual panels, two on sides, one on top. 4 AERL peak power trackers.

Type of Solar Panel: Three fixed flat panels.
Panel Voltage: 84 volts

Notes and Reported Problems During the Race: Bad instrumentation, low batteries from Day 1 through Day 6. Practiced 241 km (150 mi) before the race.

27th Place

Car: #500—University of Puerto Rico. "Discovery". Dept. of Mech. Eng., Mayaguez, Puerto Rico 00681 (809) 265-3826, FAX (809) 265-3817
Time: 91.10 hrs
Avg. Speed: 19.60 kph (12.18 mph)
Penalties: 31.783 hrs
Days Finished Before 6:30 p.m.: 1
Total Distance: 1052.5 km (654.0 mi)
Country: Puerto Rico

Team Captains: Marcos Batista, Hector Justiniano
Faculty Advisors: Dr. David Serrano, Jorge Luis De Ritis, Andres Diaz
Team Members: Jose L. Rivera, Wee Liam Fung, Luis Tirado, Manuel Micheli, Linda Quiles, Johana Castro
Cost: $20,000
Project Time: 1 year
Qualifying Speed: 37.0 kph (23.0 mph), 16th
Avg. Race Speed: 19.6 kph (12.2 mph)
Best Daily Avg. Speed: 33.7 kph (20.9 mph)
Slowest Daily Avg. Speed: 14.2 kph (8.8 mph)
Daily Average Speed kph(mph):
1 21.09(13.11)
2 16.86(10.48)
3 24.26(15.08)
4 16.35(10.16)
5 14.16(8.80)
6 25.0(15.54)
7 33.69(20.94)

Weight w/o Driver: 291 kg (642 lb)
Length: 5.8 m (19 ft)

Width: 2 m (6.6 ft)
Height: 1.37 m (4.49 ft)
Wheelbase: 2.4 m (7.87 ft)
Track Width: 1.52 m (4.99 ft)
Clearance: 0.20 m (0.66 ft)

Wheels and Tires: 36 spoke, 51 cm (20 in) wheels with spoke covers; Avocet Fasgrip free style 51 cm x 4.4 (20 x 1.75 in) slick tires @ 85 psi
Number of Wheels: 3
Est. Tire Rolling Resistance Coefficient: 0.0055
Number of Flat Tires During the Race: 1

Brakes, Suspension, and Steering: Morrison go cart, cable adjusted disk brakes, three wheels. Rear cable/disc emergency brake Regenerative Brake. Single A arm front with Solo-Flex exercise machine spring and damper. Rear trailing arm with Solo-Flex damper. Lever and cable steering mechanism.
Chassis: Aluminum tubing space frame, with fiberglass body.
Motor: Solectria DC brushless, 6 kW rated, 11 kW max, 6000 RPM, 120 volts, 12.3 kg, 92% efficient at operating power level, 94% peak efficiency. Blower cooling.
Controls and Instrumentation: Amp hour counter, speed and odometer.
Transmission: Direct drive timing belt, 4.4/1 reduction.

Batteries: Sears, 10 batteries, 120 volts, 4.2 kWh, 210 lb, 95 kg (210 lb).
Solar Cells: Brand X solar cells purchased from Solectria, Monocrystalline Silicon, 648 cells, 14% single cell rated efficiency, 450 watts peak. 1 Solectria peak power tracker.

Type of Solar Panel: Flat fixed tilting panel
Panel Voltage: 84 volts

Notes and Reported Problems During the Race: Low battery from Day 1 to Day 6, only able to travel part of each day and spent the rest of each day charging. Car packed in three crates for shipping to start. No mechanical or electrical failures during the race. Lowest cost vehicle participating in the race. Practiced 805 km (500 mi) before the race.

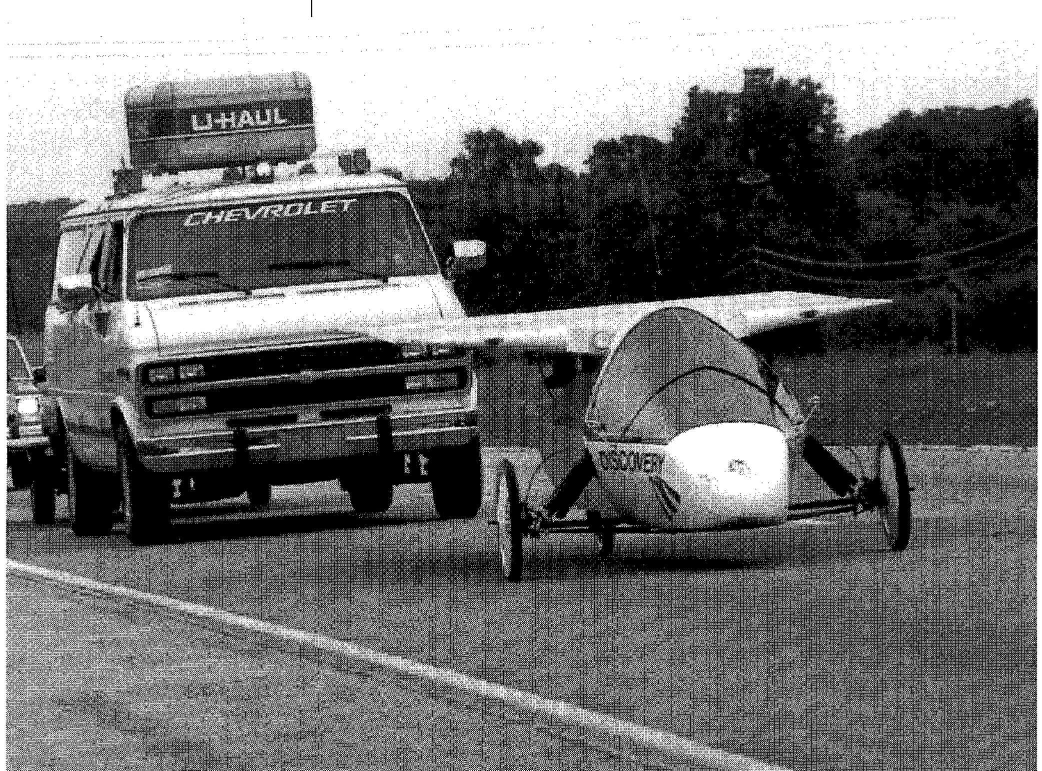
Penalties: 33.086 hrs
Days Finished Before 6:30 p.m.: 2
Total Distance: 1057 km (656.8 mi)
Country: USA

Team Captains: William P. Dryland, Tad H. Guski
Faculty Advisors: Francis Badlam, Dr. Russell Read, Dr. Eric Thacher
Team Members: Pierre Devaux, Troy Hetherington, Forrest Deitz, Brett Johnson, Matthew Johnson, Paul Kronenwetter, Paul Labella, Scott Martin, Mark Morel, Dan Retajczyk, Joe Rizza, Ludwig Tarkowski, Doug Walrath, Tim Vile, Paul Kronenwetter
Cost: $52,000
Project Time: 2 years

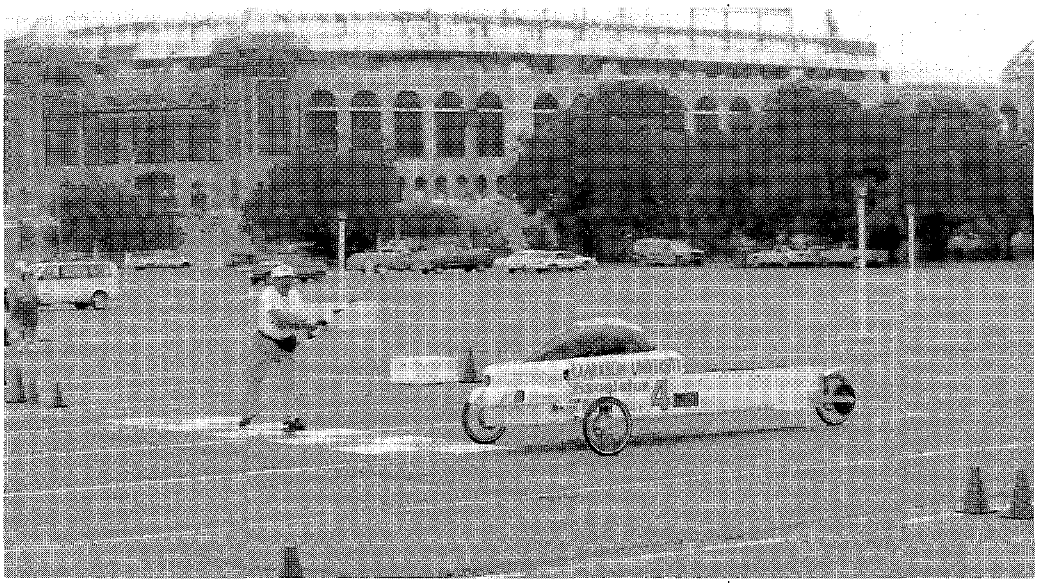
Drag Coefficient, Cd: 0.30
Frontal Area A: 0.7 m² (2.30 ft) **Drag Area CdA**: 0.21 m² (0.69 ft) Estimate only.
Qualifying Speed: 40.0 kph (24.8 mph), 33rd
Avg. Race Speed: 19.4 kph (12.1 mph)
Best Daily Avg. Speed: 34.0 kph (21.1 mph)
Slowest Daily Avg. Speed: 14.0 kph (8.7 mph)
Daily Average Speed kph(mph)
1 21.13(13.13)
2 14.03(8.72)
3 22.43(13.94)
4 17.01(10.57)
5 15.06(9.36)
6 29.91(18.59)
7 33.94(21.10)

28th Place

Car: #4—Clarkson University. "Excelsior". MAE Department, Potsdam, NY 13699-5725 (315) 268-3970, FAX (315) 268-6438
Time: 91.85 hrs
Avg. Speed: 19.44 kph (12.08 mph)



27th Place - University of Puerto Rico



28th Place - Clarkson University

Weight w/o Driver: 245 kg (540 lb)
Length: 6 m (19.7 ft)
Width: 2 m (6.6 ft)
Height: 1.1 m (3.6 ft)
Wheelbase: 2.59 m (8.5 ft)
Track Width: 1.52 m (4.99 ft)
Clearance: 0.20 m (0.66 ft)

Wheels and Tires: 48 spoke, 51 cm (20 in) wheels; Haro 51 x 4.4 cm (20 x 1.75 in) slick tires @ 85 psi
Number of Wheels: 3
Est. Tire Rolling Resistance Coefficient: 0.0060
Number of Flat Tires During the Race: 2

Brakes, Suspension, and Steering: Pro-Stop hydraulic disk front brakes, cable actuated mountain bike hydraulic disc brakes rear. Regenerative Brake. Single A arm front with inboard nitrogen charged gas shocks/springs. Rear trailing arm with nitrogen charged shocks/spring. Rack and Pinion steering.
Chassis: Monocoque, Kevlar/PVC Foam panel and body.
Motor: Solectria brushless DC, 6 kW rated, 12 kW max, 6000 RPM, 120 volts, 10.5 kg (23.15 lb), 87% efficient at operating power level, 92% peak efficiency.
Controls and Instrumentation: Solectria motor controller. Constant power cruise control. Switchable, digital readout of operating functions. Telemetry to chase van, including environmental cab temperature.
Transmission: Electric series/parallel windings field switch gives 2/1 motor speed reduction. Direct #35 chain drive to rear wheel with 4/1 ratio.
Batteries: Pulsar, 10 batteries, 120 volts, 4.8 kWh, 100 kg (220 lb)
Solar Cells: 50% BP, 50% Astro Power Solar Cells, Monocrystalline Silicon, 760 cells, BP—17% single cell rated efficiency, Astro Power—13.9% single cell rated efficiency, estimated peak panel efficiency 14%, 4 parallel strings. 2 Solectria and 1 AERL peak powertrackers. 800 watts peak. 56.13 (35 mph) on 1000 watts input to motor.

Type of Solar Panel: Flat fixed panel.
Panel Voltage: 95 volts

Notes and Reported Problems During the Race: Hit road reflector, bent suspension push rod and broke spokes. Loose connection, low batteries Day 1 through Day 5. Couldn't charge battery Day 2, regulator bad. Ampere hour meter and telemetry system burned out day 7. Instrumentation burned out on Day 4, not waterproof. Practiced 241 km (150 mi) before the race.

29th Place

Car: #42—University of Missouri, Rolla. "Sol Survivor". 113 EE, Rolla, MO 65401 (314) 341-6443, FAX (314) 341-4532
Time: 96.12 hrs
Avg. Speed: 18.57 kph (11.54 mph)
Penalties: 36.9533 hrs
Days Finished Before 6:30 p.m.: 1
Total Distance: 929.7 km (577.7 mi)
Country: USA

Team Captains: Jeff Shapiro, Tom Sullivan, Paul Stalman, Aaron Laws
Faculty Advisors: Dr. Norman Cox, John Tyler
Team Members: Doug Henneken, Rob Ziegler, Gary Pinkley, Matt Spaethe, Rick Jenkins, Dennis Myer, Rick P. Pardun.
Cost: $120,000
Project Time: 2 years

Drag Coefficient, Cd: 0.15
Frontal Area A: 1.5 m^2 (16.2 ft^2)
Drag Area CdA: 0.225 m^2 (2.43 ft^2) 1/10th scale wind tunnel model.

Qualifying Speed: 43.6 kph (27.1 mph), 20th
Avg. Race Speed: 18.5 kph (11.5 mph)
Best Daily Avg. Speed: 32.7 kph (20.3 mph)
Slowest Daily Avg. Speed: 15.0 kph (9.3 mph)
Daily Average Speed kph(mph)
1 17.14 (10.65)
2 16.03 (9.96)
3 24.27 (15.09)
4 15.38 (9.56)
5 14.99 (9.31)
6 22.61 (14.05)
7 32.68 (20.31)

Weight w/o Driver: 308 kg (678 lb)

Length: 6 m (19.7 ft)
Width: 1.8 m (5.9 ft)
Height: 1.3 m (4.3 ft)
Wheelbase: 2.5 m (8.2 ft)
Track Width: 1.5 m (4.9 ft)
Clearance: 0.15 m (0.49 ft)

Wheels and Tires: 36 spoke, 51 cm (20 in) wheels with spoke covers; Avocet Fasgrip Freestyle 51 x 4.4 cm (20 x 1.75 in) slick tires @ 110 psi
Number of Wheels: 4
Est. Tire Rolling Resistance Coefficient: 0.0055
Number of Flat Tires During the Race: 1

Brakes, Suspension, and Steering: Double A arm spring over Carrera 160 shocks. Trailing arm in rear, same shocks. Rack and Pinion steering.
Chassis: Chrome/moly steel 3.18 cm (1.25 in) tubing space frame 0.89 cm (0.035 in) thick wall. Kevlar/Carbon honeycomb body.
Motor: Uniq DC brushless, 7.5 kW rated, 15 kW max, 4200 RPM, 100 volts, 25 amps running, 7 kg (15 lb), 90% efficient at operating power level, 92% peak efficiency. Blower cooling.
Controls and Instrumentation: Constant speed cruise control. Telemetry of operating functions to chase vehicle.
Transmission: Custom 2 speed gear transmission, 3 kg (7 lb), includes neutral. Tooth belt 2.25/1 ratio to rear wheel.

Batteries: Trojan/Eagle Picher, seven batteries plus two auxiliary, 84 volts, 4.8 kWh, 55 ah, 95 kg (210 lb).
Solar Cells: BP Solar Cells, Monocrystalline Silicon, 935 cells, 17% single cell rated efficiency, 1000 watts peak. 1 AERL plus 6 student designed and built peak power trackers.

Type of Solar Panel: Fixed panel with a five gently warped facets.
Panel Voltage: 84 volts
Notes and Reported Problems During the Race: Low battery power for 6 days. Low array power due to cracked cells. Transmission shifter failed. Motor surging due to telemetry transmission signal interfering with motor controller. Shorted motor, power surge. Practiced 80 km (50 mi) before event.

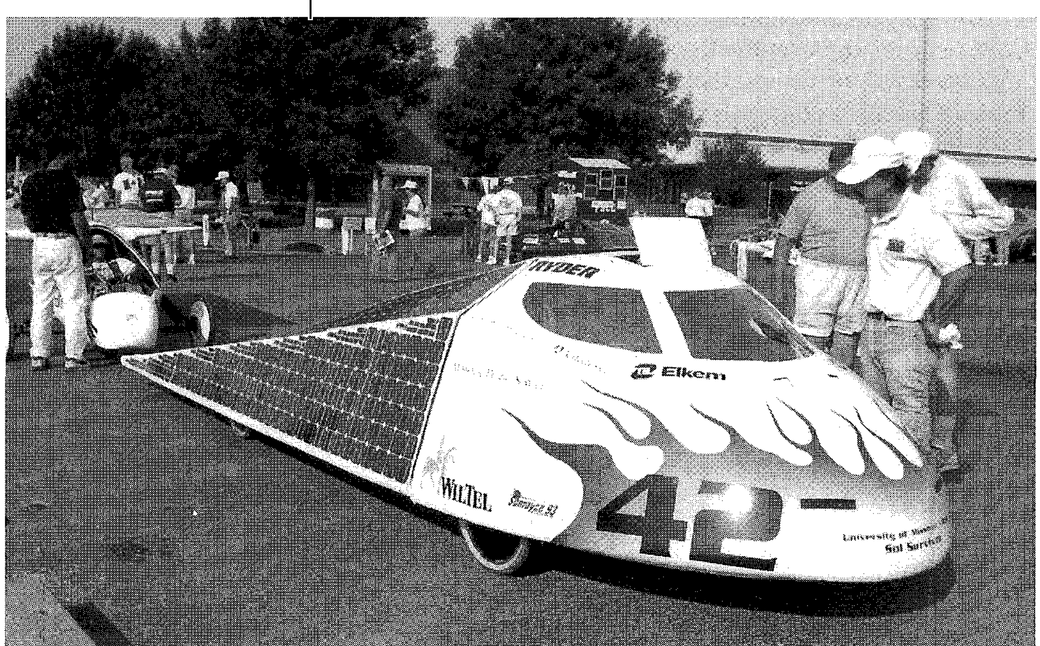
30th Place

Car: #90—Mercer University. "SunScream". Mech. Eng.,1400 Coleman Ave., Macon, GA 31207 (912) 752-2534, FAX (912) 752-2166
Time: 96.29 hrs
Avg. Speed: 18.54 kph (11.52 mph)
Penalties: 37.03 hrs
Days Finished Before 6:30 p.m.: 1
Total Distance: 921.8 km (572.8 mi)
Country: USA

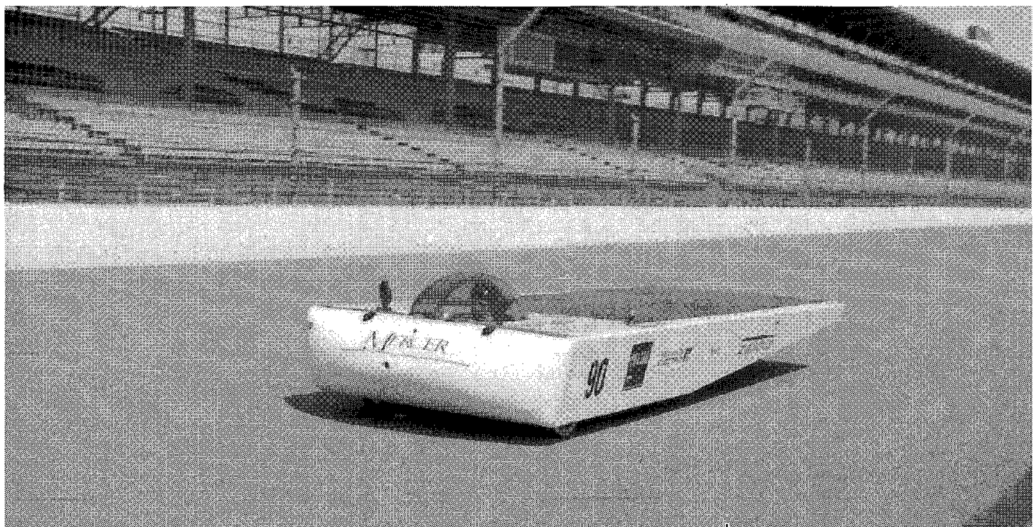
Team Captain: Michael P. Reardon
Faculty Advisors: Dr. John Schaefer, Dr. Thomas Cook, Mr. Jack Mahaney
Team Members: Jonny Hodges, Bob Timberlake, Scott Waters, Jay Marsh, Robbie Guest, Craig Anderson, Ruth Cook, Daniel Duston, Alaa Eljallad, Lee Hammond, Johnny Hodges, Jason Jackson, Mike Lake, Travis McCallum, Lynn Mercer, Prof. John Wallace, Tom Wheeler
Cost: $100,000
Project Time: 1 1/2 years

Qualifying Speed: 20.0 mph, 32.2kph, 17th
Avg. Race speed: 18.5 kph (11.5 mph)
Best Daily Avg. Speed: 34.1 kph (21.2 mph)
Slowest Daily Avg. Speed: 15.1 kph (9.4 mph)
Daily Average Speed kph(mph)
1 16.89(10.50)
2 15.09(9.38)
3 26.77(16.64)
4 18.03(11.21)
5 15.17(9.43)
6 18.10(11.25)
7 34.19(21.25)

Weight w/o Driver: 400 kg (882 lb)
Length: 6 m (19.7 ft)
Width: 2 m (6.6 ft)
Height: 1 m (3.3 ft)
Wheelbase: 2.7 m (8.9 ft)
Track Width: 1.42 m (4.7 ft)



29th Place - University of Missouri, Rolla



30th Place - Mercer University

Clearance: 0.15 m (0.63 ft)

Wheels and Tires: 36 spoke, 51 cm (20 in) wheels; Avocet Fasgrip Freestyle 51 x 4.4 cm (20 x 1.75 in) slick tires @ 100 psi
Number of Wheels: 3
Est. Tire Rolling Resistance Coefficient: 0.0055
Number of Flat Tires During the Race: 2

Brakes, Suspension, and Steering: Wilwood front hydraulic disk front brakes, rear Honda C150 disc brake, regenerative brake. Unequal length double A arms front, rear trailing arm Koni shocks with special coil springs. Ford Escort rack and pinion steering.
Chassis: Carbon/foam composite body with fiberglass/foam composite array support. Space frame was welded aluminum tubing.
Motor: Reliance DC brushless, 1.5 kW rated, 2000 RPM, 120 volts, 18.2 kg (40 lb), 88% efficient at operating power level.
Controls and Instrumentation: Constant speed cruise control. Telemetry of twenty operating functions.
Transmission: Continuously variable transmission cone/belt with electronic control speed change, .2.2/1, 8/1 ratios.

Batteries: GNB Pulsar, 10 batteries, 120 volts, 4.99 kWh, 41 ah, 100 kg (220 lb)
Solar Cells: BP Solar Cells, Monocrystalline Silicon, 828 cells, 17% single cell rated efficiency, overall panel efficiency 14%, 1200 watts peak. 4 strings. 4 student designed and constructed peak power trackers.

Type of Solar Panel: Fixed flat panel.
Panel Voltage: 85 volts
Reported Maximum Instantaneous Panel Power During Race: 1200 W

Notes and Reported Problems During the Race: Day 6, broke canopy, canopy restraint and 43 cells due to canopy latch failure. Batteries completely depleted on Day 1 due to total failure of instrumentation system. CVT highly inefficient, replaced motor and transmission with Solectria fixed ratio 2 stage transmission. Excessive spoke failure due to higher than anticipated weight. Lost nearly three days between problems with the transmission, array, and wheels. Practiced 322 km (200 mi) prior to the race.

31st Place

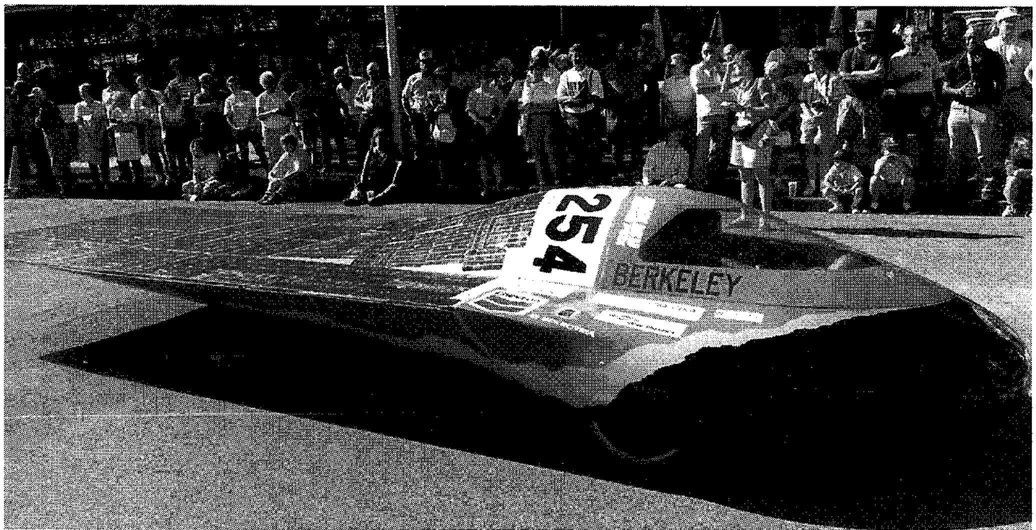
Car: #254—University of California, Berkeley. "California Dreamin". 245 Hesse Hall, Berkeley, CA 94720 (510) 642-5701, FAX (510) 642-5713
Time: 98.43 hrs
Avg. Speed: 18.14 kph (11.27 mph)
Penalties: 38.397 hrs
Days Finished Before 6:30 p.m.: 1
Total Distance: 876.7 km (544.8 mi)
Country: USA

Team Captains: Spencer Quong, Jonathan Beck
Faculty Advisor: George Johnson
Team Members: Iain Shigeoka, Hieu Ta, Ivan Huang, Charles Sullivan, David Azevedo, Ben Tsai
Cost: $80,000
Project Time: 2 1/2 years.

Drag Coefficient, Cd: 0.16
Frontal Area A: 1.2 m² (13.0 ft²)
Drag Area CdA: 0.192 m² (2.1 ft²) 1/8th scale wind tunnel model.

Qualifying Speed: 35.3 kph (22.0 mph), 24th
Avg. Race Speed: 18.2 kph (11.3 mph)
Best Daily Avg. Speed: 28.2 kph (17.5 mph)
Slowest Daily Avg. Speed: 13.1 kph (8.1 mph)
Daily Average Speed kph(mph)
1 28.21(17.53)
2 18.12(11.26)
3 14.01(8.71)
4 13.08(8.13)
5 16.14(10.03)
6 16.50(16.47)
7 27.19(16.90)

Weight w/o Driver: 335 kg (739 lb)
Length: 6 m (19.7 ft)
Width: 2 m (6.6 ft)
Height: 1 m (3.3 ft)
Wheelbase: 2.4 m (7.9 ft)
Track Width: 1.3 m (4.3 ft)
Clearance: 0.13 m (0.43 ft)
Wheels and Tires: 36 spoke, 51 cm (20 in) wheels with spoke covers; Avocet Freestyle 51 x 3 cm (20 x 1.25 in) slick tires @ 100 psi



31st Place - University of California, Berkeley

Brakes dragging, day 5, drained battery. Practiced 161 km (100 mi) before race.

32nd Place

Car: #36—University of Texas, Austin. "Texas Native Sun". Dept. of Mech. Eng., ETC 5.160, Austin, TX 78712 (512) 471-3120, FAX (512) 471-10457
Time: 101.99 hrs
Avg. Speed: 17.51kph (10.88mph)
Penalties: 42.3361 hrs.
Days Finished Before 6:30 p.m.: 1
Total Distance: 803.8 km (499.5 mi)
Country: USA

Team Captains: Joe Thoennes, Roy Nangoy
Faculty Advisor: Gary Vliet
Team Members: James Herrera, Steve Trindade, Chet Krushefski
Cost: $80,000
Project Time: 1 1/2 years.

Drag Coefficient, Cd: 0.13
Frontal Area A: 1.2 m (13.0 ft^2)
Drag Area CdA: 0.156 m^2 (1.68 ft^2)
1/6th scale wind tunnel model.
Qualifying Speed: 34.9 kph (21.72 mph), 27th
Avg. Race Speed: 17.5 kph (10.9 mph)
Best Daily Avg. Speed: 17.5 mph, 28.1 kph
Slowest Daily Avg. Speed: 8.1 mph, 13.0 kph
Daily Average Speed kph(mph)
1 18.23(11.33)
2 15.93(9.95)
3 19.03(11.83)

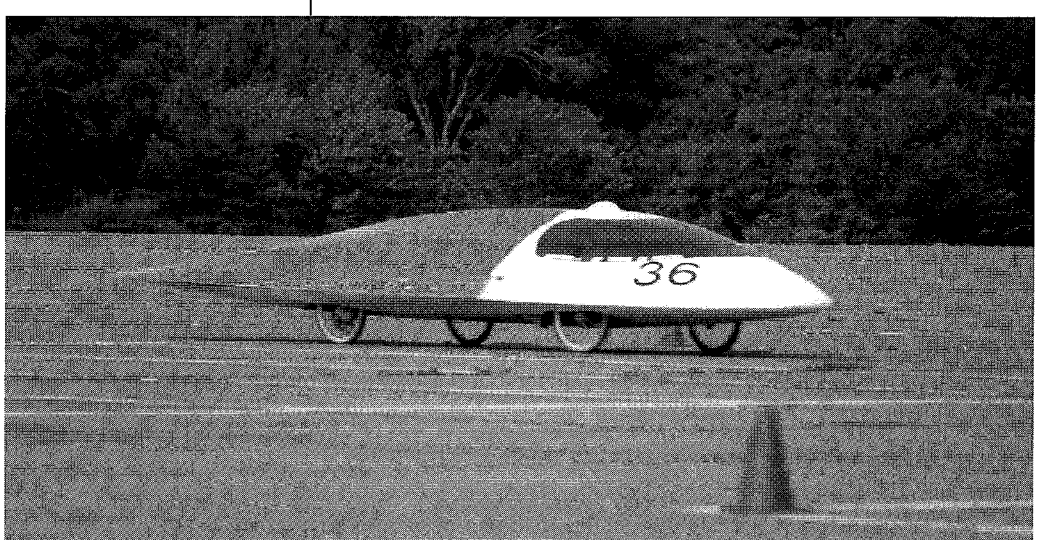
Number of Wheels: 3
Est. Tire Rolling Resistance Coefficient: 0.0055
Number of Flat Tires During the Race: 0

Brakes, Suspension, and Steering: Double A arm air spring over shock. Rear trailing arm, same shock. Ackerman geometry rack and pinion steering.
Chassis: Carbon tube space frame. Fiberglass/Carbon body with foam ribbing.
Motor: Solectria DC brushless, 5 kW rated, 10 kW max, 6000 RPM, 60 volts, 150 amps, 13.6 kg (30 lb), 91% efficient at operating power level, 94% peak efficiency. Blower cooling.
Controls and Instrumentation: Constant speed cruise control. Cab display of operating functions. Telemetry to chase vehicle.
Transmission: Direct drive chain sprocket.

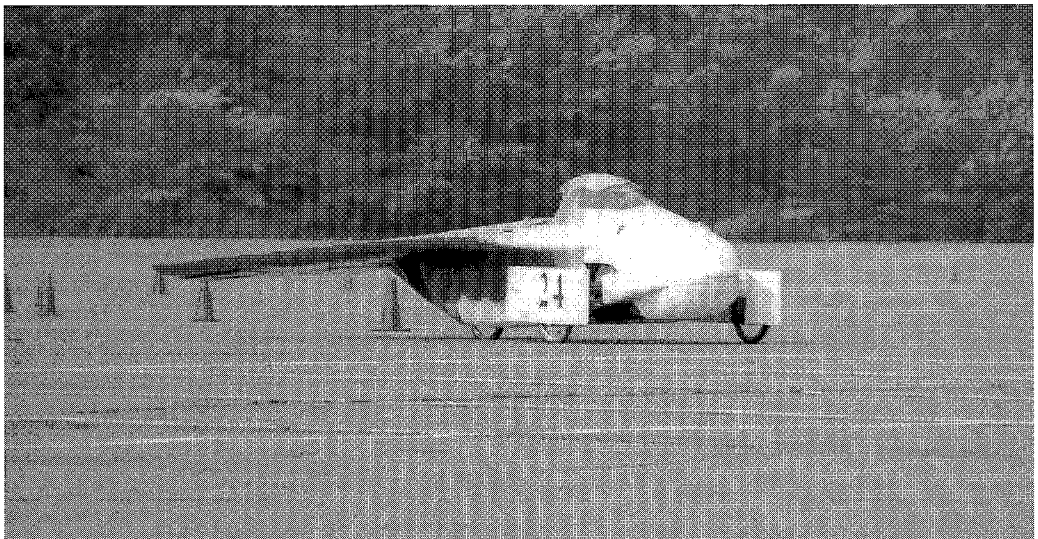
Batteries: Trojan, 5 batteries, 60 volts, 4.8 kWh, 40 ah, 95 kg (210 lb).
Solar Cells: Siemens solar cells, Monocrystalline Silicon, 670 cells, 13% single cell rated efficiency, 9 strings, 9 student designed and constructed peak power trackers.

Type of Solar Panel: Fixed flat panel with solar cells mounted on rear of canopy. **Panel Voltage**: 40 volts

Notes and Reported Problems During the Race: Crashed following van, lost one day in trailer repair. Blew two controllers. Low power from panel and low batteries six days. Hit railroad tracks, broke front suspension king pin. Lost a day in suspension repair.



32nd Place - University of Texas, Austin



33rd Place - University of Waterloo

4 13.00(8.08)
5 17.06(10.60)
6 20.08(12.48)
7 28.11(17.47)

Weight w/o Driver: 308 kg (680 lb)
Length: 6 m (19.7 ft)
Width: 2 m (6.6 ft)
Height: 1 m (3.3 ft)
Wheelbase: 2.36 m (7.7 ft)
Track Width: 1.19 m (3.9 ft)
Clearance: 0.20 m (0.66 ft)

Wheels and Tires: 36 spoke, 51 cm (20 in) wheels with spoke covers; Tioga Comp. Pool, 51 x 3 cm (20 x 1.25 in) slick tires @ 80 psi
Number of Wheels: 4
Est. Tire Rolling Resistance Coefficient: 0.0055
Number of Flat Tires During the Race: 4

Brakes, Suspension, and Steering: Front cable actuated tandem bicycle disk brakes. Rear left drum brakes regenerative brake, rear right. Double A arm front with racing technology mountain bike air spring/shocks. Rear transverse fiberglass leaf spring with mountain bike shocks. Rack and Pinion.
Chassis: Carbon monocoque beam and bulkhead frame. Carbon/fiberglass body.
Motor: Uniq DC brushless, 7.5 kW rated, 15 kW max, 4000 RPM, 96 volts, 120 amps max., 4.5 kg (10 lb), 87% efficient at operating power level. Blower cooling.
Controls and Instrumentation: Cab display of operating functions.
Transmission: Fixed gear ratio chain drive to right rear wheel.

Batteries: Power Sonic, 6 batteries, 72 volts, 3.6 kWh, 50 ah, 95 kg (210 lb).
Solar Cells: Solarex solar Cells, Polycrystalline Silicon, 900 cells, 95% areal packing, 13% single cell rated efficiency. 1000 watts peak. 8 strings. 8 Solectria peak power trackers.

Type of Solar Panel: Six gently warped facets.
Panel Voltage: 35 volts

Notes and Reported Problems During the Race: Electrical short first day, changed entire power system. Continual problems with drive shaft, broken spline joints. Panel wiring problem detected and corrected the morning of the fourth day. Problem with front wheel camber caused excessive tire wear. Needed to replace about a dozen tires. Very little practice with current car before race.

33rd Place

Car: #24—University of Waterloo. "Midnight Sun". Systems Design Eng., 200 University Ave. West, Waterloo, Ontario, Canada N2L 3G1 (519) 885-1211 x 2978, FAX (519) 746-4791
Time: 108.16 hrs
Avg. Speed: 16.50 kph (10.26 mph)
Penalties: 44.7933 hrs.
Days Finished Before 6:30 p.m.: 1
Total Distance: 668.0 km (415.1 mi)
Country: CANADA

Team Captains: David Swan, Peter Mroz, Jordan Smith
Faculty Advisor: Dr. Gordon J. Savage
Team Members: Peter Mroz, Jordan Smith, Dan Vacca, Jason Ryu
Cost: $100,000 CAN
Project Time: 1 1/2 years.

Drag Coefficient, Cd: 0.19
Frontal Area A: 1.2 m (13 ft^2)
Drag Area CdA: 0.23 m^2 (2.5 ft^2) 1/6 scale wind tunnel model.

Qualifying Speed: 35.1 kph (21.8 mph), 28th
Avg. Race Speed: 16.5 kph (10.3 mph)
Best Daily Avg. Speed: 24.1 kph (15.0 mph)
Slowest Daily Avg. Speed: 13.2 kph (8.2 mph)
Daily Average Speed kph(mph)
1 17.28(10.74)
2 13.26(8.24)
3 17.65(10.97)
4 15.77(9.80)
5 14.05(8.73)
6 20.14(12.52)
7 24.07(14.96)

Weight w/o Driver: 362 kg (799 lb)
Length: 5.8 m (19 ft)
Width: 1.96 m (6.43 ft)
Height: 1.3 m (4.27 ft)
Wheelbase: 2.5 m (8.2 ft)
Track Width: 1.8 m (5.9 ft)
Clearance: 0.15 m (0.49 ft)

Wheels and Tires: 48 spoke, 51 cm (20 in) wheels with spoke covers and fairings; Avocet (17 **(with 20" wheels??)** x 1.25 in) slick tires @ 90 psi
Number of Wheels: 3
Est. Tire Rolling Resistance Coefficient: 0.0055

Brakes, Suspension, and Steering: Hydraulic Honda motorcycle disk front brakes, bike caliper rear brake. Double A arm front suspension, with coil over shock. Rear trailing arm, with single coil over shock. Bell crank to dual link steering.
Chassis: 6061-T6 Aluminum tubing space frame. Kevlar/foam sandwich body.
Motor: Solectria DC brushless, 1.5 kW rated, 4.5 kW max, 4500 RPM, 48 volts, 17.7 kg (39 lb), 89% efficient at operating power level. Blower cooling.
Controls and Instrumentation: Minimum instrumentation. Radio voice communication only to following van.
Transmission: Double reduction, chain drive to rear wheel, 6/1 ratio.

Batteries: GNB batteries, 4 batteries, 48 volts, 4.4 kWh, 92 ah, 114 kg (252 lb).
Solar Cells: Astro Power, monocrystalline silicon, 720 cells top, 144 cells bottom, 15% single cell rated efficiency, 5 series strings. 5 student designed and built peak power trackers.
Type of Solar Panel: Fixed flat top panel with two panels underneath.
Panel Voltage: 75 volts

Notes and Reported Problems During the Race: Low battery power 1st through 6th day. Trailered entire distance second day. Practiced 290 km (180 mi) before race.

34th Place

Car: #49—New Mexico Institute of Mining and Technology. "Zia Roadrunner". 601 Park Street, Socorro, NM 87801 (505) 835-5708, FAX (505) 835-5707
Time: 117.80 hrs
Avg. Speed: 15.11 kph (9.42 mph)
Penalties: 30 min.
Days Finished Before 6:30 p.m.: 1
Total Distance: 542.7 km (337.2 mi)
Country: USA

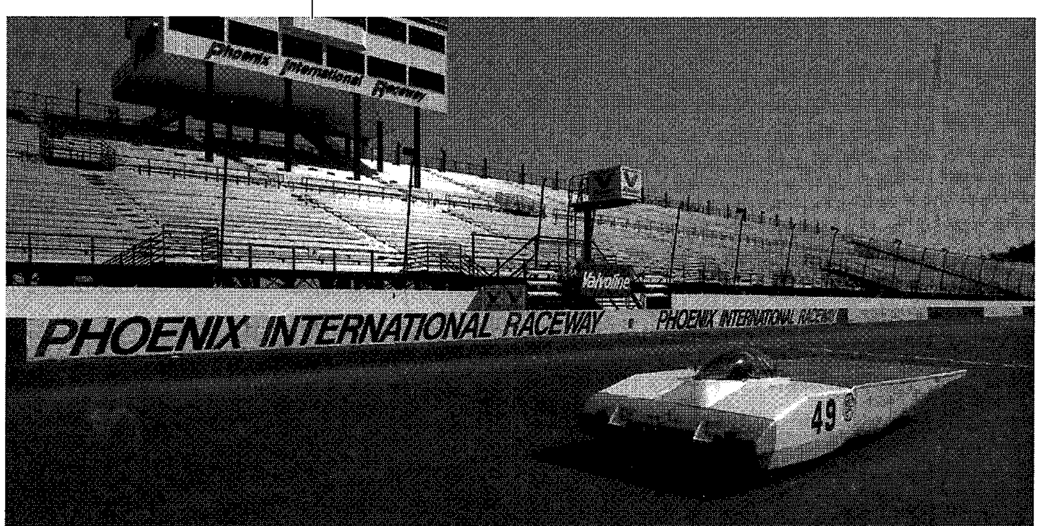
Faculty Advisor: Colin W. Wightman
Team Members: Casey Caddell, Brian Lukow, David Calkins, Michael Munroe
Cost: $27,000
Project Time: 4 months

Qualifying Speed: 51.3 kph (31.9 mph), 14th
Avg. Race Speed: 15.1 kph (9.4 mph)
Best Daily Avg. Speed: 16.1 kph (10.0 mph)
Slowest Daily Avg. Speed: 14.0 kph (8.7 mph)
Daily Average Speed kph(mph)
1 15.53 (9.65)
2 16.12 (10.02)
3 15.16 (9.42)
4 14.01 (8.71)
5 14.99 (9.31)
6 15.09 (9.38)
7 15.74 (9.78)

Weight w/o Driver: 400 kg (882 lb)
Length: 6 m (19.7 ft)
Width: 2 m (6.6 ft)
Height: 1.2 m (3.6 ft)
Wheelbase: 2.79 m (9.15 ft)
Track Width: 1.57 m (5.15 ft)
Clearance: 0.13 m (0.43 ft)

Wheels and Tires: 36 spoke, 51 cm (20 in) wheels; ACS 51 x 4.4 cm (20 x 1.75 in) Freestyle slick tires @ 100 psi
Number of Wheels: 3
Est. Tire Rolling Resistance Coefficient: 0.0055

Brakes, Suspension, and Steering: Hydraulic motor cycle disk front brakes, bike hydraulic caliper brake rear. Regenerative Brakes. Front uneven A arms, with Monroe air shock/spring.



34th Place - New Mexico Institute of Mining and Technology

Trailing arm rear, with Monroe shocks. Rack and pinion steering.
Chassis: Central carbon/foam box beam frame. Carbon/foam/ fiber glass body.
Motor: Uniq 086 DC brushless, 3.4 kW rated, 4.5 kW max, 5000 RPM, 84 volts, 45 amps, 3.6 kg (8 lb), 85% efficient at operating power level, 88% peak efficiency. Natural convection cooling.
Controls and Instrumentation: Constant speed cruise control. Telemetry of voltages, currents, temperatures, speed to chase van.
Transmission: Direct cog belt drive to rear wheel, 7.5/1 reduction.

Batteries: Interstate 22 NF, 7 batteries, 84 volts, 4.4 kWh, 104 kg (230 lbs).

Solar Cells: Siemens, Monocrystalline Silicon, 666 cells, 14% single cell rated efficiency, 550 watts peak. 4 strings of 9 modules each. 1 Solectria peak power tracker.

Type of Solar Panel: Fixed flat panel.
Panel Voltage: 80 volts

Notes and Reported Problems During the Race: Two controllers failed (Uniq and Solectria), Hawaii loaned NM a controller so they could finish the day. Motor bad. First day, array not hooked up, ran out of power. Low battery, days 1 through 6. Practiced only 8 km (5 mi) before the race.