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Broader Perspectives

EVENT REPORT
Sunrayce 99

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During June 1999, 29 university teams from Canada and the US raced their solar-powered cars 2280 km from Washington DC to Orlando, Florida in the Sunrayce 1999 event. In spite of its name, the race was noteworthy for its lack of sunshine. The challenging and unpredictable weather served to add another dimension to the fiercely competitive race, which is high-profile solar energy showcase. The conditions favoured teams with a superior energy management strategy over outright performance, with many cars able to cover great daily distances at reasonable speeds in spite of the Spartan amount of energy available. The race was won by the University of Missouri–Rolla with an average speed of about 40 km h^{-1}. Copyright © 2000 John Wiley & Sons, Ltd.

THE EVENT

The first Sunrayce event was conducted in 1990 and since then it has become a prestigious biennial university event sponsored primarily by General Motors Corporation, The US Department of Energy and Electronic Data Systems (EDS).† The race is open to universities and colleges from North America, and for the first time a special invitation was extended to a Japanese team, from Tokyo Institute of Technology. The basic spirit of the regulations is simple. The cars' motors must be powered by solar energy alone, either provided directly from the solar array or temporarily stored in batteries. The batteries store energy that is collected during stationary periods and from regenerative braking. The solar array must be less than 8 m^2 in area, and made from commercially available solar cells of North American origin, with a cost of less than US$10 per watt.

Each car is rigorously scrutinised to ensure that high standards of safety and roadworthiness are met, then each vehicle must drive 160 km on a closed-loop course in less than 4 h to qualify. Sunrayce 99 regulations had several updates from the 1997 race, including a 'cut-out rule' which allowed teams to locate the driver's windshield and canopy within the area of the solar array without incurring any performance penalty. As a result, cars were generally shorter and better handling than in previous years, and therefore safer.

Teams were permitted 140 kg of lead–acid batteries, or for those teams who could afford the substantial cost premium, nickel–metal–hydride batteries were also permitted to a maximum weight of 80 kg. Cars were required to have four wheels with minimum separation distances to ensure driver control could be maintained in the event of a tyre blowout.

The race is held in daily stages, with cars starting each daily stage at one-minute intervals from 9 a.m. in order of their finish in the previous day's racing. The cumulative elapsed time determines the overall standings. If a team is unable to complete a stage, their race time for that day is calculated as 8 h plus 1·5 min per mile of distance trailered (8 h + 56 s km^{-1}). All cars must be at the finish point for the day in time to be impounded at 8:30 p.m. Once impounded, the car cannot be

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touched until 5 a.m. The impound rule is intended as a safety measure to ensure that teams get a good night's sleep instead of working through the night without rest, something adrenaline-fuelled students are often known to do. However, this regulation was completely ineffective at helping the team strategists sleep well! Cars are allowed out from impound in time to catch the sunrise, with charging then allowed until the race starts.

During on-road racing, there are harsh penalties if the speed limit is broken. Average speeds were mostly well below the speed limits, but the course included long downhill runs where the cars could have easily coasted at 100 km h^{-1} or more, but were limited by legal limits of 60 km h^{-1}. Great care and diligence were required by the drivers not to violate this rule.

THE RACE

The race route followed the foothills of the Appalachians, from Washington DC through Virginia and the Carolinas, and then followed the rolling plains of Georgia and Florida, using state highways (Figure 1). This was more densely populated and more mountainous terrain than in previous events, and these factors combined with the weather made for an interesting contest. The densely populated area was preferred by race organisers and sponsors because of the improved publicity and exposure this affords.

The University of Missouri–Rolla and Queen's University were locked in a fierce contest for the lead throughout the entire race. Figure 2 illustrates the average speed each day for the top cars, showing how these two teams jockeyed back and forth. In the end, Missouri–Rolla won by just 47 min.

The battle to fill the three remaining top-five positions was extremely fierce, with Rose Hulman Institute of Technology, University of Minnesota and Iowa State University constantly trading positions throughout the race. University of Missouri–Columbia steadily made their way up the field and finished in a creditable 6th position. Messiah College, École de Technologie Supérieure, Kansas State University, and University of Waterloo rounded out the top 10.

The remaining teams completing the race were, in order: Ohio State University, University of Pennsylvania, Stanford/Berkeley, Clarkson University, Yale University, University of Oklahoma, University of Michigan, University of North Dakota, Minnesota State University–Mankato/Winona, University of Toronto, Lincoln Land Community College, Purdue University, Western Michigan University, University of Arizona, South Dakota School of Mines and Technology, Principia College, University of Virginia, New Mexico Institute of Mining and Technology, and United States Military Academy.

All of the top 10 cars were exceptionally reliable, so strategic decisions on when to save or spend battery power were of the highest importance. Many teams came prepared for the 'no budget' race conditions encountered in Sunrayce 95[1] and 97[2], where cars drove all day as fast as the rules would permit, and could still finish with energy to spare. In those two previous races, reliability was the largest determining factor between the front-running teams and small differences in vehicle efficiency and strategy were insignificant. This year's return to an emphasis on efficiency and strategy

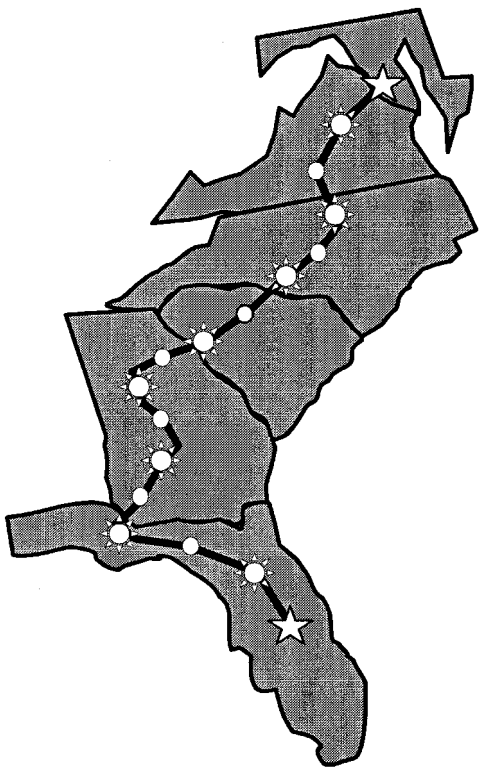

Figure 1. Route taken by Sunrayce 99 from Washington DC to Orlando, Florida[1]

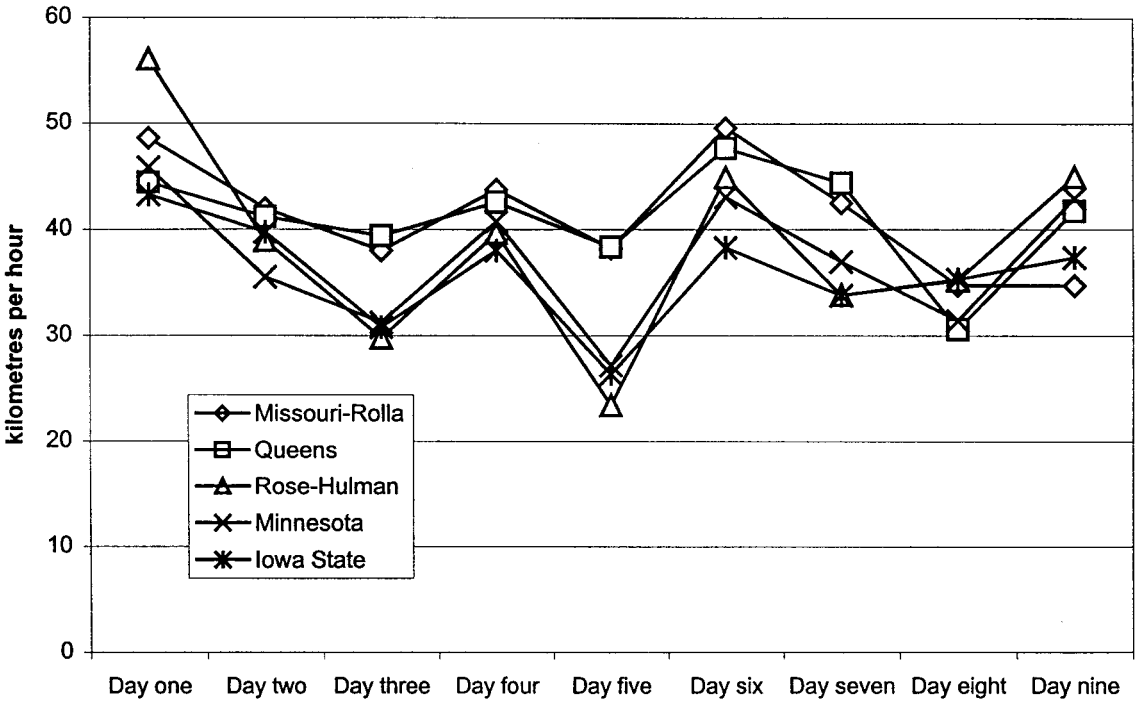

Figure 2. Average daily speed of the top five teams

made it more similar to the Sunrayce events held in 1990[3] and 1993[4].

STRATEGY

The strategy involved in a wet-weather race differs considerably from one that is raced under sunny conditions. The factors that result in a team finishing the day in a top position tend to depend more on the ability of the team to manage the power they have available as opposed to the ability of the car to travel fast. Teams that had little or no on-road testing prior to the race suffered as a result. A detailed knowledge of the car's battery pack and the efficiency of the car at low speeds was a considerable advantage.

The teams used two main strategies over the course of the race. Missouri–Rolla and Queen's, who finished first and second, used a strategy that relied heavily on the ability to charge at the end and beginning of each day. They travelled to the finish line as fast as possible, allowing them the advantage of extra charging time. Pre-race testing allowed them to predict the speed that would get them to the finish line as quickly as possible and still retain a safe margin of battery reserve. This prediction was based on formulas involving factors such as weather, battery charge, array power and motor current.

The other strategy used was 'race to finish', where teams calculated the minimum speed that they had to travel to finish the day's leg within the allowed race time. While the 'race to finish' strategy provided a safeguard against bad weather the following day, it cost these teams most of their charging time at the end of each day. This slowly diminished the charge in their batteries over a period of days, resulting in huge trailering penalties and an increasing gap between the two leaders and the rest of the field.

In previous Sunrayce events the average speeds were fast enough for aerodynamic efficiency to be extremely important. The aerodynamic regime favours more powerful vehicles, even if they are heavier.[5] This year, however, the race speeds were much lower and vehicle weight was a dominant factor. Many vehicles carried 'dead-weight' in batteries that they could never recharge. These heavier vehicles suffered despite their potential for higher power. Queen's University made a decision to carry less than the maximum allowed battery

Figure 3. Queen's University at the race finish

Figure 4. Start of the race, Washington, DC

weight, diminishing the dead-weight they carried. The decision to do this was a large risk. Had the weather improved, the weight-power trade-off would have worked against them as the speed increased.

THE SOLAR ARRAYS

The factor limiting the efficiency of the solar cells used in Sunrayce 99 was that the price could not exceed US$10/W and the cells had to be

Figure 5. Charging at Lowes speedway, Charlotte, North Carolina

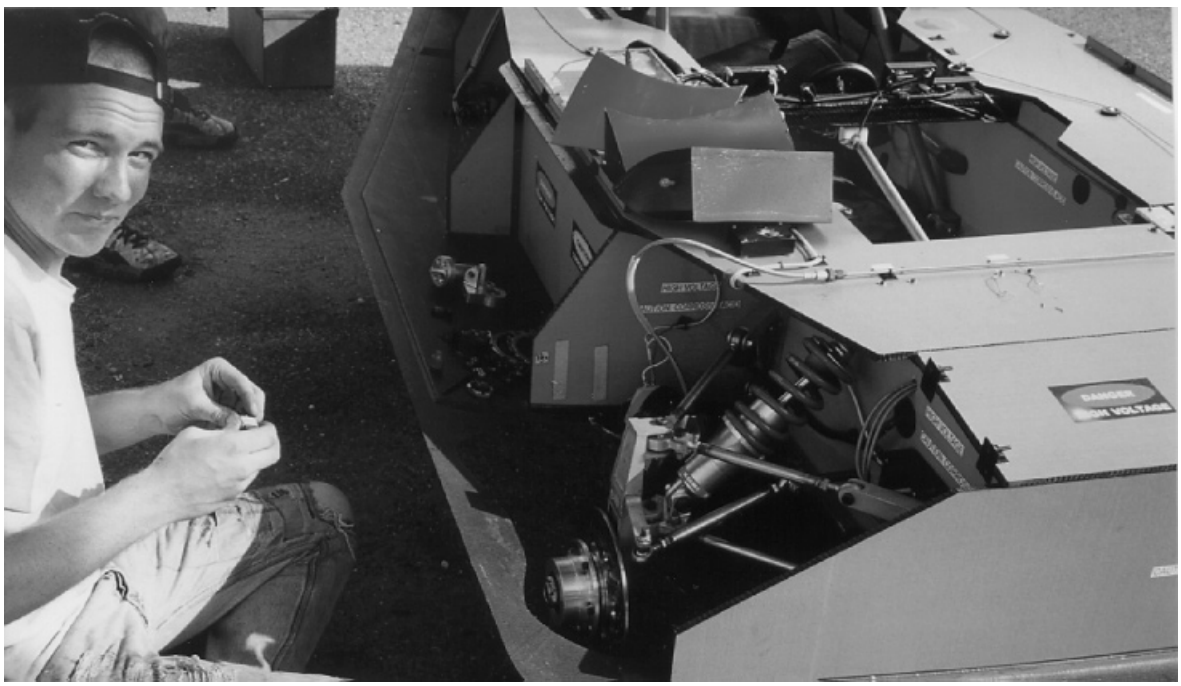

Figure 6. Iowa State student at work prior to the race

manufactured in North America. Such cells have an efficiency that is typically in the vicinity of 13–14%. This year, the Tokyo Institute of Technology from Japan was invited to participate in Sunrayce 99, the first time a team from outside North America has been allowed to compete for a spot in the event. As guests of the event, the Tokyo team was excused from the solar technology limitation rule and they used Daido Hoxan cells manufactured in Japan with over 15% efficiency. Unfortunately, they did not pass scrutineering and thus were not permitted to compete. Had they done so, the area of their array would have been physically masked to compensate for the higher efficiency cells.

Missouri–Columbia won this year's prize for the 'Best Array'. Building on the process they developed for their 8th position Sunrayce 97 entry, the

Figure 7. Typical weather for Sunrayce 99

team constructed an extremely efficient array with an aerodynamically sound finish on both the surface and edges.

University of Minnesota was the only top-10 finisher that used shingling in their array. Shingling can be advantageous because it allows better packing density and higher voltages to be produced. Very few teams employ this method because of the great skills and care that is required to get it right, and the very real risk of making an array of lower power if the highest standards are not met. Aerodynamics and light weight are also harder to achieve with a shingled array.

Race winner Missouri–Rolla had their panels manufactured professionally and then laid over the shape of their car. PVC netting held the cells together but allowed flexibility for the placing of each panel. While their array was not as aerodynamic as previous race winners, the lower speeds of this year's race diminished the importance of aerodynamics relative to other factors.

The main suppliers of solar cells for the race were ASE Americas and Siemens Solar Industries. For Sunrayce 97 most of the better teams used ASE cells, although the top two teams used Siemens. This year, five of the top 10 teams used ASE, four

Table I. Top 10 teams for Sunrayce 99

Position	Car no.	Team	Time (h:min:s)	Average speed ($km\ h^{-1}$)
1	42	University of Missouri–Rolla	56:16:44	40·7
2	100	Queen's University	57:04:02	40·2
3	74	Rose-Hulman Institute of Technology	64:08:10	35·7
4	35	University of Minnesota	64:24:13	35·6
5	9	Iowa State University	65:28:13	35·0
6	43	University of Missouri–Columbia	66:00:13	34·7
7	77	Messiah College	69:43:06	32·9
8	101	École de Technologie Supérieure	70:03:58	32·7
9	11	Kansas State University	70:23:48	32·6
10	24	University of Waterloo	72:42:15	31·5

used Siemens (including race winner Missouri–Rolla) and Queen's used cells manufactured by Solec International.

FUTURE DIRECTIONS

For the race in 2001, it has been formally proposed that the solar technology limitation based on cost be lifted and a maximum power output be applied instead. This new rule would allow teams to participate in Sunrayce with more efficient solar cells. The benefit of such a rule is that a team can build a car with the high-efficiency cells needed to be competitive in international races, and simply mask-off a portion of the array for Sunrayce. By restricting the power available to each car, the organisers hope that teams who can afford only low-cost solar cells will not be disadvantaged. However, there is a considerable aerodynamic advantage to having a smaller array, so a team intent on winning Sunrayce would still want to use the best, most expensive cells available. It will be difficult for the organisers to develop a power-limit rule that meets all of their objectives.

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