Broader Prospectives

EVENT REPORT

Brain Sport: The 1996 World Solar Challenge *Solar Car Race Across Australia*

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In November 1996, a field of 46 solar cars left Darwin bound for Adelaide, some 3000 km to the south. The first car to complete the course, the Honda Dream, set a new race record, maintaining an average speed of 89.9 km per hour (56 mph) over the 4 days. This report describes the highlights of the race and discusses the solar cell and array technology used by the leading cars. © 1997 by John Wiley & Sons, Ltd. Progr. Photovolt. 5: 69–76, 1997

(No. of Figures: 6. No. of Tables: 1. No. of Refs: 6.)

BACKGROUND

Every 3 years since 1987, a field of up to 50 solar cars has left Darwin in northern Australia and headed south on the torturous 3000 km trans-continental race to Adelaide. The race passes through some of the most arid and isolated, yet starkly beautiful, regions of the planet (Figure 1). The cars race from 8.00 am and teams camp by the roadside at the spot they reach at 5.00 pm.

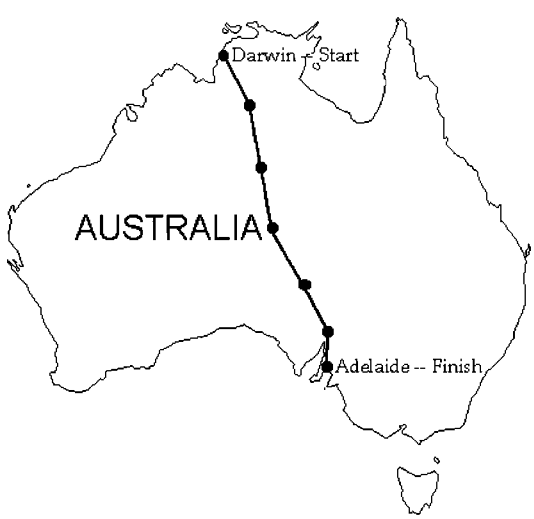

Figure 1. Map of Australia showing race course. (Map courtesy of Simon Toh, Department of Mining, Minerals and Materials Engineering, University of Queensland)

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The race was the brainchild of adventurer Hans Tholstrup who refers to solar car racing as brain sport. Part of the reason for the success of this event has been Tholstrup's ability to inspire others with his vision of the race as a means of promoting the development of cleaner, more efficient and more sustainable technologies.

As with former events,[1–4] the participants in the 1996 race included teams from major motor corporations, universities and high schools, complemented by a number of private entries, some with a somewhat eccentric flavour. The 1993 race had completely smashed the standards set by the General Motors Sunraycer in the inaugural 1987 event[1] and pre-race expectations were that a similar quantum leap in performance might be expected from the 1996 event.

RULES AND REGULATIONS

Tholstrup has worked to keep rules and regulations to a minimum to encourage maximum creativity. There is a limit to the size of the cars (they must fit into a box 6 m $\times$ 2 m $\times$ 1.6 m high, roughly the dimensions of a large family car), the size of the solar array (roughly 8 m^2 in plan area for a single-seater car and 12 m^2 for a two-seater) and battery capacity (nominally 5 kWh, as subsequently discussed). The driver and passenger (if applicable) are each weighted to 80 kg. As previously mentioned, the cars race from 8.00 am to 5.00 pm, but can charge their batteries from their on-board solar arrays outside these hours.

Refinements in the rules for the 1996 race were that battery capacity was constrained by limiting the weight of a battery of any given type (more easily measured than its capacity!). For example, Ag/Zn batteries, preferred by the top contenders, were limited to a weight of 40 kg, corresponding to the 5 kWh capacity for the particular type of cells generally used. Competitors preferring more rugged Ag/Zn batteries of higher weight/capacity ratio were thereby limited to a capacity of less than 5 kWh. The second change was the extension of the period spent at six of the seven media stops scattered along the course from 10 min to 30 min, to give those following the race in conventional vehicles a better chance of keeping in contact. Since the solar arrays still operate during these stops, this change does not significantly alter the amount of solar energy collected during the race. It would be expected to result in less efficient use of this energy due to it being expended more quickly between stops. This change would therefore be expected to increase the total time taken to complete the course but also to increase the average speed while the car was in motion.

THE RACE

Pre-race favourites were three experienced teams equipped with the most efficient solar arrays yet seen in the race. These were: Honda Research and Development, winners of the 1993 event; Aisin Seiki, another large budget Japanese team who had competed in the 1990 event and who are suppliers to the automotive industry, particularly to Toyota; and the Aurora Vehicle Association, placed fifth in the 1993 event but with a greatly improved vehicle for 1996. The car developed by the University of Biel and placed second in the 1993 event had also been entered in the 1996 event by a union of colleges in the Biel-Bienne region of Switzerland. This was an extremely reliable vehicle, which was expected to do well, but possibly to be out-gunned by the sheer power of the previous three contenders. Waseda University, fourth in the 1993 event, had converted its car to a two-seater with an enlarged array area, and was also expected to be very competitive.

During the speed and stability trials on the day before the race, used to establish starting positions, the Honda vehicle showed its class clocking a record 135 km h^{-1}. The Biel car was next fastest at 118 km h^{-1}, with the French team Helios clocking the third fastest time of 112 km h^{-1}.

The race started in Darwin at 8.00 am on Sunday 27th October, on a clear day with scattered clouds. Honda was first to Katherine, 314 km away, averaging an impressive 93.3 km h^{-1}. Biel was second with a surprisingly fast average of 89.3 km h^{-1} and Aisin Seiki was third with a speed of 80.2 km h^{-1}. There had been a surprisingly high drop-out rate amongst the top teams on this first leg. The Waseda University car had 'stalled' on the start-line, where it was to stay for 45 min. The local favourite, the Desert Rose from the Northern Territory University, seventh in 1993, travelled only a few kilometres down the road before running into rouble with its motor controller. One of the hot favourites, the Aurora Q1, improved its position from ninth to fourth place before running into a series of problems 25 km down the road, where the car stayed until it was withdrawn the following day.

During the day, the first three cars further increased their lead over the field and also the distance between one another. This was to be the continuing theme for the race until, by the second or third day, the reliability of these three cars and the professionalism of the teams supporting them made any change in position extremely unlikely. The interest in the front-runners shifted to whether or not Honda would meet its target of completing the 3000 km course in less than 4 days.

However, many a fierce battle was fought to determine the remaining top 10 positions and positions further down the field. After stalling at the starting line, Waseda University blazed through most of the field on the first day and then more steadily improved this position to sixth by the end of the race. After reaching only the 100 km mark after the first day, the team of the Desert Rose worked overnight to have the car in working order by the start of racing the next day. They then began an even more impressive charge through the field, finishing in seventh position and averaging over 70 km h^{-1} for the remainder of the course.

A long and protracted battle for fourth spot was fought between Osaka Sangyo University, the University of Queensland and Mitsubishi Materials Corporation, the eventual victor.

A buffeting south-easterly wind on the second day of the race exposed the susceptibility of the Honda car to 'fish-tailing', limiting its gain over the Biel car and preventing it from setting a new distance record on this day. Conditions on the third day were perfect, with the Honda car averaging 94.4 km h^{-1} but still falling short of the race record for the distance travelled in 1 day. As if to emphasize the improvements in solar car design brought about by the Challenge, the Honda car camped that night at the same idyllic knoll reached by the GM Sunraycer at the end of the fourth day of the inaugural event.

The next day, the Honda car set out to complete the remaining 744 km to the finishing line in the 8 h of racing available to it on the day. By the time the car left the final checkpoint, it had 2 h 58 min to complete the remaining 298 km (3 h 08 min without incurring a time penalty). At 50 km from the finish line, the car was cruising at 100 km h^{-1} accompanied by a swarm of media and a helicopter or two, and the desired result seemed very achievable. However, by 20 km out, the car had drained every ounce of energy from its battery and was travelling along a highway shaded by trees and other traffic, powered only by the rapidly failing sunlight. Fortunately, the Honda car had the highest performance solar array ever assembled on board, which proved up to the task. In a final flurry, the car crossed the finish line at 5.26 pm (race time), incurring a 16 min time penalty. Even with this penalty, its average speed over the course had been a record 89.9 km h^{-1}.

The Biel team made it to within 220 km of the finish on the same day. On the next, with charged batteries, it zoomed to the line as quickly as speed limits would allow. The Aisin Seiki team crossed the line 2 h after.

With the early attrition of some of the potential front runners, there was then a gap of nearly a day until the fourth-placed Mitsubishi crossed the line on the sixth day, followed by Queensland University, Waseda University, the fast finishing Northern Territory University and then Osaka Sangyo University. The University of New South Wales finished the next day to take ninth position. Queen's University of Canada, in eleventh position, was the first North American team to cross the line.

The reason for the relatively poorer performance of the North American university teams than in the 1990 and 1993 events can be attributed to a loss of synchronization between the timing of the US Sunrayce and the present race. This not only resulted in fewer North American entrants but reduced the race-hardness for those that did enter. Japanese teams, on the other hand, had time to 'iron out the bugs' in pre-challenge events such as the Akita Grand Challenge.

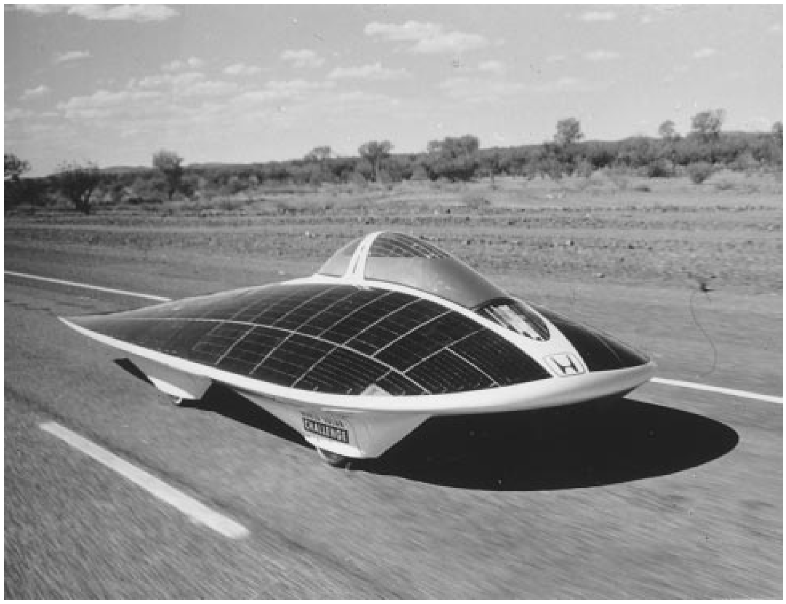

Figure 2. The Honda Dream two-seater; outright winner

CAR DESIGN

The solar array becomes the most important component of the car only when other design features such as aerodynamics, weight, rolling resistance and motor and battery efficiency have been satisfactorily addressed. Less tangible aspects such as tactics and the level of preparation of the car and its supporting team also play a crucial role.

The simplest relationship between the power reaching the road, P, and the car velocity, V, applies for cars travelling at constant speed on flat surfaces with no wind[5]

$$P = MgC_R V + \frac{1}{2}\rho C_D A V^3 \quad (1)$$

where Mg is the weight of the car, C_R is the rolling resistance coefficient, ρ is the air density (1.2 kg m^{-3}), C_D is the aerodynamic drag coefficient and A is the frontal area of the car.

The Honda car (Figure 2) was a completely original design for this race, developed by a different group within Honda from the team which developed the 1993 winner. The new team took a confident new approach to the design of the car. Although designed as a two-seater and therefore allowed up to 12 m^2 of projected solar array area, the car used less than 10 m^2, suggesting that it is far from an optimized two-seater design. Nonetheless, the car was very high on the power parameter, P, of Equation (1), given the efficiency of its solar array (23–24% cells) and the efficiency in transferring this power to the road, aided by features such as a wheel-mounted motor. However, with the passenger representing 80 kg of human ballast, the car had a penalty with respect to Mg. The larger car size required to accommodate the extra passenger also gave a large frontal area, A, compared to other vehicles. The extra weight also encouraged a design with four wheels, increasing C_D compared to the lighter three-wheelers. It appeared that channels between the cells near the front of the car would also result in the loss of laminar flow over frontal areas, also increasing the value of C_D. Hence, the car's overwhelming advantage lay in P, as would apply to most two-seater designs.

The second-placed Biel car (Figure 3) was one of the lightest in the race and also featured some of the lowest values of rolling resistance and drag coefficients. Its frontal area, however, was higher than other

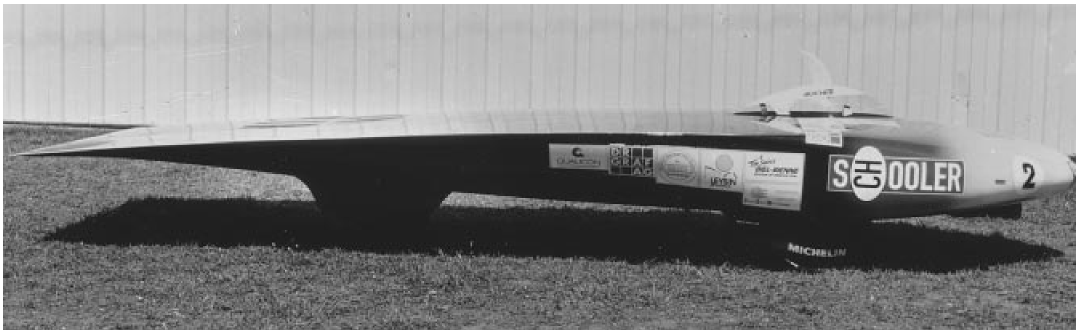

Figure 3. The United High Schools Biel-Bienne 'sCHooler': second overall and first in the single-seater category

Figure 4. The Aisin Seiki 'Aisol III'; third outright

designs and its array output, although the fourth most efficient in the race, gave 20–25% lower output than possible using the best available cells.

The third-placed Aisin Seiki car (Figure 4) adopted a design similar to the original GM Sunraycer. It had a low frontal area but was intermediate between the first two cars in most other parameters. An innovative feature of the car was the use of a wheel-mounted switched reluctance motor. Its efficiency was reported as 91%, which is creditably close to the 96–98% efficiency reported for the best permanent magnet wheel-mounted motors used in the race. The fifth placed car from the University of Queensland was the first 'low budget' car home, winning the lead acid battery class as well as using standard screen-printed Sharp cells. It made up for its higher weight and lower power by a low frontal area, A, and a low drag coefficient, C_D.

Although a new race record was set during the present race, the above discussion suggests that there is still scope for quite marked performance increase. An average speed of 100 km h^{-1} throughout the race is likely to be achieved either in the next or subsequent race, given good weather.

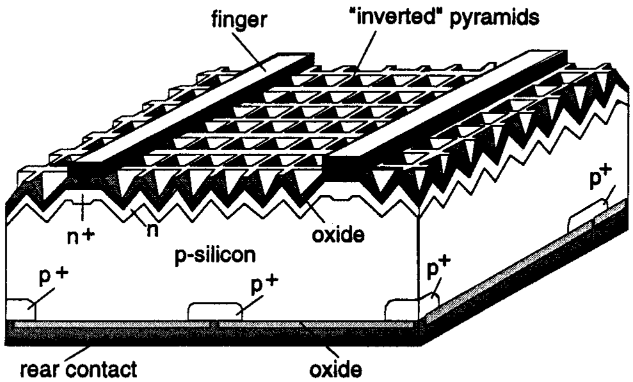

Figure 5. The PERL (passivated emitter, rear locally-diffused) cell structure

CELL AND ARRAY TECHNOLOGY

One of Hans Tholstrup's aims in establishing the Challenge was to accelerate the development of the technologies involved. The race has been outstanding in meeting this aim.

In the cell area, it has provided an incentive for taking results from the laboratory into pilot and full-scale production. For the 1993 event, SunPower established a production capacity for 21–22% efficient cells to supply the winning car.[6] For the 1996 event, SunPower supplied an additional two cars with cells of a similar or even slightly higher performance while the University of New South Wales through Unisearch Ltd, the University's commercial arm, supplied 23–24% efficient cells for the winning Honda car. The University also supplied 22–23% cells for the third-placed Aisin-Seiki car and for the ill-fated Aurora vehicle. For each of the 1993 and 1996 events, the array on the winning car has set a new world record for the efficiency of a solar array of this size with efficiencies of 20–21% and 22–23%, respectively, demonstrated.

The new performance levels in the present race were set by the UNSW PERL (passivated emitter, rear locally-diffused) cells of Figure 5. Cells with an average 23.1% efficiency taken early from the production run and encapsulated by the University had earlier established a new record of 22.3% efficiency for a photovoltaic module of any description. A set of similar performance cells encapsulated by Gochhermann Solar Technology using a surface texturing technology similar to that attempted on the Biel car subsequently gave a slightly higher efficiency of 22.7%. Encapsulating higher performance cells made later in the production process should see the photovoltaic module efficiency pushed beyond the 23% mark for the first time.

All top three cars and several others in the race used a shingled cell approach, such as the brickwork shingle of Figure 6 used by the Biel car. An innovation introduced by the Honda team was the use of an antireflection coating applied to the smooth encapsulating layer over the top of the cells. This antireflection coating was applied by a dipping process. The surface texturing approaches used by several cars in the previous race[1] were also used again by several competitors.

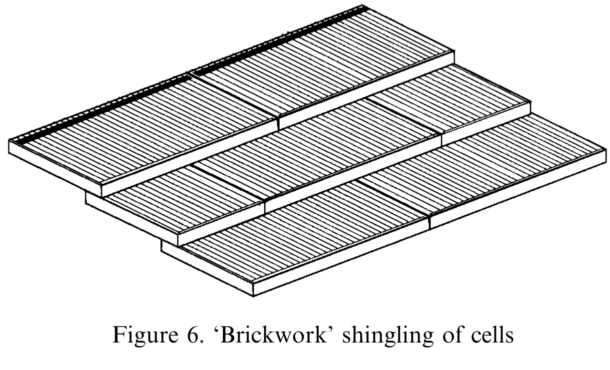

Figure 6. 'Brickwork' shingling of cells

Table I. Summary of finishers on fourth, fifth and sixth day of racing

Place	Team	Country	Av. speed (km h^{-1})	Cell efficiency (%)	Array power[a] (W)	Array features
Day 4 finisher						
1	Honda R & D	Japan	89.9	23.5	1900[b]	• UNSW PERL cells • AR-coated array • 1D shingling
Day 5 finishers						
2	Biel-Bienne	Switzerland	86.0	18.8	1440	• Deutsche Aerospace cells • High-efficiency Cz space cells • Brickwork shingling
3	Aisin Seiki	Japan	80.7	22.5	1760	• UNSW PERL cells • 2D shingling
Day 6 finishers						
4	Mitsubishi	Japan	66.7	17	1260	• ASE (Germany) cells • Gochermann encapsulated
5	Queensland Uni.	Australia	64.9	15.5	1200	• Sharp screen-printed cells
6	Waseda Uni.	Japan	64.6	15.5	1640[b]	• Sharp screen-printed cells • Shingled array • Some portions textured
7	North Territory Uni.	Australia	62.7	18.5	1360	• UNSW buried-contact cells
8	Osaka Sangyo Uni.	Japan	60.4	15.5	1200	• Sharp screen-printed cells

[a]Under standard test conditions (AM1.5, 100 mW cm^{-2}, $T = 25°C$).
[b]Two-seater giving larger array area.

Table I lists the finishers on the fourth, fifth and sixth days of racing, emphasizing cell and array parameters. Most of the other entrants used standard screen-printed cells supplied by Sharp, Siemens Solar, Showa Shell, ASE Americas, BP Solar, Kyocera, Astropower, Solel, Hoxan or Neste.

One or two cars used space cells, with the Japanese Crested Ibis team using Kaneka amorphous silicon cells. Although limited to about 600 W of power from the array, this beautifully prepared car managed to complete the course in 8 days, averaging a creditable 44.6 km h^{-1}. To add to the spectacle, two of its team members were married at the finish line. These would not be the only two young people for whom the race represented one of the most important events in their lives so far.

CONCLUSION

The 1996 World Solar Challenge consolidated the outstanding progress demonstrated in the 1993 event. With the extremely high performance cells now available and the scope for improvement in other features of the participating solar cars, it is obvious that even faster events will be held in the future. In a departure from past timing, the event will now be held every 2 years, with the next due in November 1998.

The race not only continues to encourage development of both solar and electric vehicle technology, but also plays an important role in exposing the general public to these developments and, importantly, in interesting young people in careers in science and engineering.

Acknowledgements

The author acknowledges the help of the many individuals who have provided information for this report. In the interests of timeliness, it was written only a few days after the first car crossed the line. The author apologies for any inaccuracies which have occurred as a result. The Photovoltaics Special Research Centre was established and supported under the Australian Research Council's Research

Centres Program. The Centre will be preparing the official technical report[5] for the race (purchasing details are available from the author or from the Centre's world wide web site at http://www.pv.unsw.edu.au/.).

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