Delft's solar car wins Solar Challenge 2003

Swathe of orange in Adelaide

Nuna II, the Dutch solar car, in the middle of Australia during the 7th World Solar Challenge.

Some thirty solar cars from twelve countries were competing with each other over a distance of 3010 kilometres, right through Alice Springs at the heart of Australia.

by Joost van Kasteren

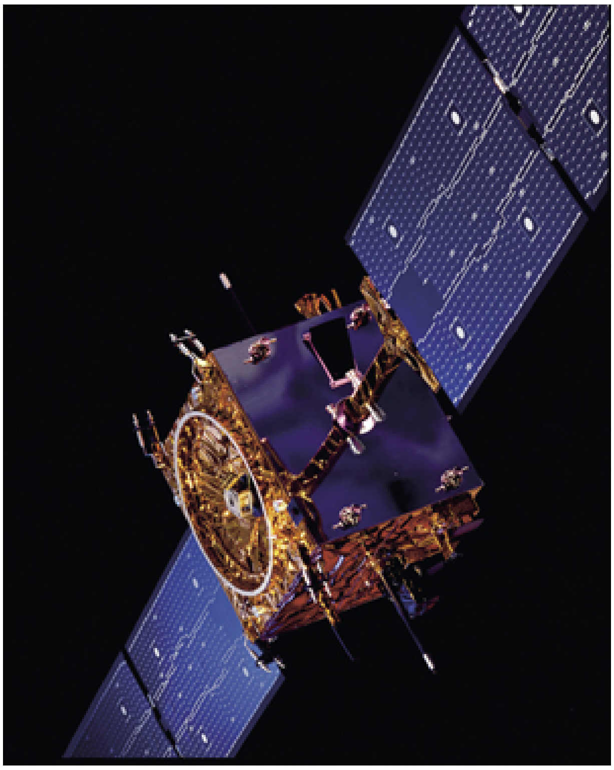
There were remarkable scenes in Adelaide, Australia, on the afternoon of Wednesday 22 October 2003 when a swathe of orange spilled through the city. Barely visible at the heart of this burst of colour was the Nuna II, a futuristic vehicle which had just won the Solar Challenge 2003, a four-day journey of more than 3000 kilometres across Australia's Outback.
The victorious team, made up mainly of students from Delft University of Technology, had just won the race, in the process proving their ability to make the most efficient use of the sun's rays to propel a vehicle.

The orange swathe that spilled through Adelaide was the throng of supporters of the Dutch team that had just won the Solar Challenge, a race for solar cars which is run every two years over the Stuart Highway that connects Darwin in the north of Australia and Adelaide in the south. The Nuna II covered the 3010-kilometre course in 30 hours and 54 minutes at an average speed of more than 97 km/h. The team reached the finish with a clear lead over its nearest challengers, the Aurora from Melbourne and the Solar Electric Vehicle built by the Massachusetts Institute of Technology, both of which were timed at more than ninety minutes slower.

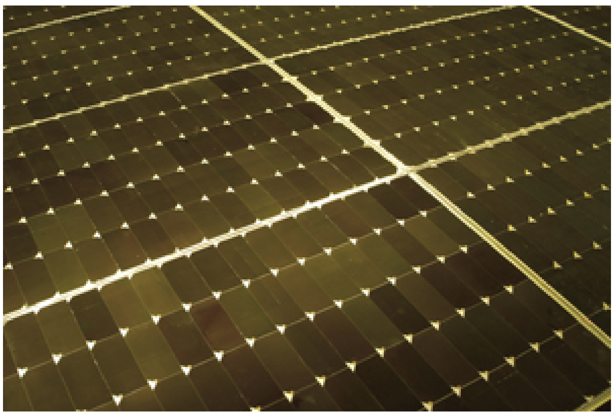
The Dutch team, most of whose members are students at Delft University of Technology, had a reputation to maintain, since two years earlier the Alpha Centauri team from Delft had shattered Honda's eight-year-old speed record and won the Solar Challenge by a large margin.
Their average speed was 91.8 km/h.
The problem with teams made up of students is that they eventually graduate and the team breaks up. This time around, however, Professor Wubbo Ockels, the Netherlands' first, and up to now only, astronaut (Space Shuttle/Spacelab 1985) brought some continuity to the team.
Within his newly formed chair Aerospace Sustainable Engineering & Technology (ASSETT) he was able to transfer the solar car racing activities from an interesting pastime for students to an academic activity.
'The decision to take part in the race in 2001 was taken by the students themselves', explains Ockels. 'At the time they asked me to act as an adviser. After they won the race I was able to arrange for some of them to be appointed as student assistants so that they could use their knowledge and experience to make a preliminary study for the successor to the Nuna. Then, together with members of the original team, I started looking for students to join a new team to develop and build the Nuna II and enter it in the race.'
The students did the work in their free time. Designing and building the Nuna II was not treated as a graduation project, although the students did receive additional credits afterwards.
Ockels: 'At the time I was still a part-time professor and was unable to arrange for the Nuna II to be accepted as a graduation project. Now I am a tenured professor and that means the members of the new team have the opportunity to combine the development and construction of Nuna II's successor with their studies.'

Monocoque
Although the Nuna II looks very similar to its predecessor there are a number of striking differences. Firstly, there is the difference in weight. The Nuna II weighs around 250 kilogrammes (excluding the 80 kilogrammes the driver must weigh under the rules), which is over 30 kilogrammes lighter than Nuna I. According to Diederik Kinds, the team leader and a student of Aerospace Engineering, the saving of weight is mainly due to the fact that the bodywork and chassis of the Nuna II are integrated to form a monocoque, a self-supporting construction in which the tubular frame has been replaced by strategically located reinforcements.
As with Nuna I, the cover of Nuna II is made from plastics reinforced with aramide, because, according to Kinds, aramide does not conduct electricity and the solar cells are located on the top of the vehicle. The

1 Motor controller 2 Max. power point tracker electronics for retrieving the maximum power from the solar cells 3 Left steering bar 4 Suspension & steering 5 Lithium-ion batteries 6 Some 28 switches are operated by the pilot 7 Pilot with headset for communication with the control vehicle 8 Solar cells (Courtesy of European Space Agency (ESA) Noordwijk, The Netherlands)



Nuna II has been fitted with the same Gallium-Arsenide (GaAs) solar cells as the recently launched European satellite SMART-1, that is now in an orbit around the Moon for observation activities and for scientific operations, such as testing miniaturised equipment. These cells have an efficiency of 27%.



main body of the monocoque is made from plastic reinforced with carbon fibre. The Nuna II is also twenty centimetres lower to the road than its predecessor and its nose is sharper and more angular, so that the Cw value, the coefficient for the air resistance, has been reduced even further to 0.09. By comparison, a passenger car has a Cw of around 0.30, a difference of a factor of 3.

Like its forerunner, Nuna II uses advanced Gallium-Arsenide (GaAs) solar cells, which have an efficiency of 27 percent, to capture sunlight. Its competitors use the same cells, which were originally developed for the space industry. For example, the ESA's recently launched SMART-1 satellite is fitted with exactly the same cells for its trip to the Moon. The GaAs solar cells on Nuna II are produced by the German manufacturer Gochermann.

According to Martijn Hinderdael, a Mechnical Engineering student, 'a special feature of the solar cells is that they have an anti-reflective coating so that more sunlight is captured when the sun is not directly overhead.' In the morning or the afternoon, when the sun is at an angle of less than 45°, sometimes half or more of the incoming rays are reflected. By adding a coating with a microstructure made up of small pyramids the reflection is reduced to roughly 5 percent.

Overtaking road trains

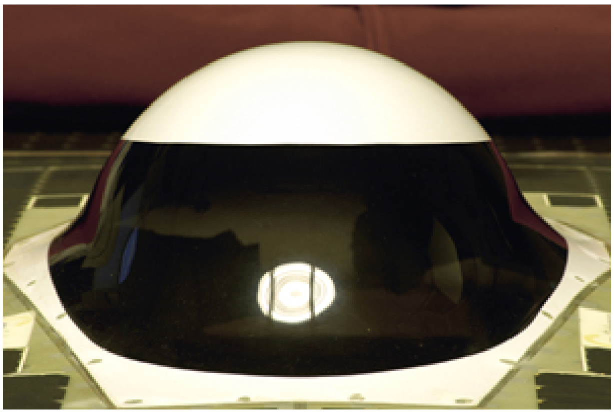
The solar cells convert the sunlight directly into electricity, which is then used to drive an electric motor, either directly or indirectly after being used to charge lithium-ion batteries. The motor is a brushless DC-current motor made in Switzerland, which is installed in the back wheel. It is a sort of reverse dynamo consisting of a classic three-phase stator and a rotor which is fitted with permanent magnets on the outside. 'During braking on the engine', explains Mark Olsthoorn, student of Aerospace Engineering, 'the so-called «regenerative» braking, the electric motor acts as a dynamo. In this way 97 percent of the kinetic energy is recovered and stored as electric power in the batteries.'

With all the improvements and modifications the Nuna II can reach a top speed of 175 km/h, 15 km/h faster than its predecessor. Its peak speed in Australia was 133 km/h, but the cruising speed was around 100-110 km/h. After all, solar cars also have to observe speed limits. Olsthoorn and Hinderdael, both of whom were drivers, are enthusiastic about the car's acceleration. The average passenger car has difficulty going from 110 to 130 km/h but Nuna II takes it in its stride. 'The pursuit cars had more difficulty overtaking those monster trucks known as road trains than we had', says Hinderdael with a grin.

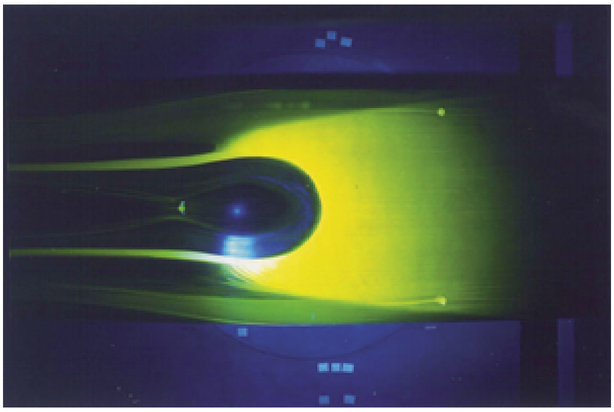
But a lot of work had to be done before the notion of overtaking road trains even arose. Nuna II arrived in Darwin at the end of September. There then followed a few weeks of tinkering, testing and tinkering again to make the car roadworthy. Because the race was taking place on public roads the car had to be tested to make sure it passed all the requirements of the Australian road traffic laws.

One of the requirements is a turning circle of 16 metres.

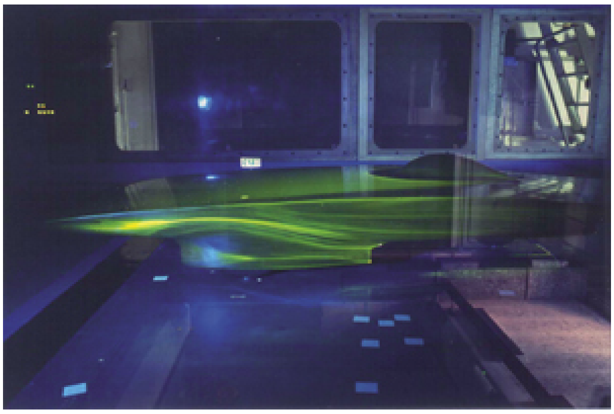
NunaII's GaAs solar cells with triangular diodes are produced by Gochermann, a company in Germany. The cells are covered with an anti-reflective coating with a microstructure of small pyramids.This allows more sunlight to be captured when the sun is at an angle of less than 45°. Without the coating more than half of the incoming rays could be reflected; that has now been reduced to roughly 5%.



To reduce the drag factor the only obstacle on the deck, the cockpit, had to have an extremely aerodynamic shape.

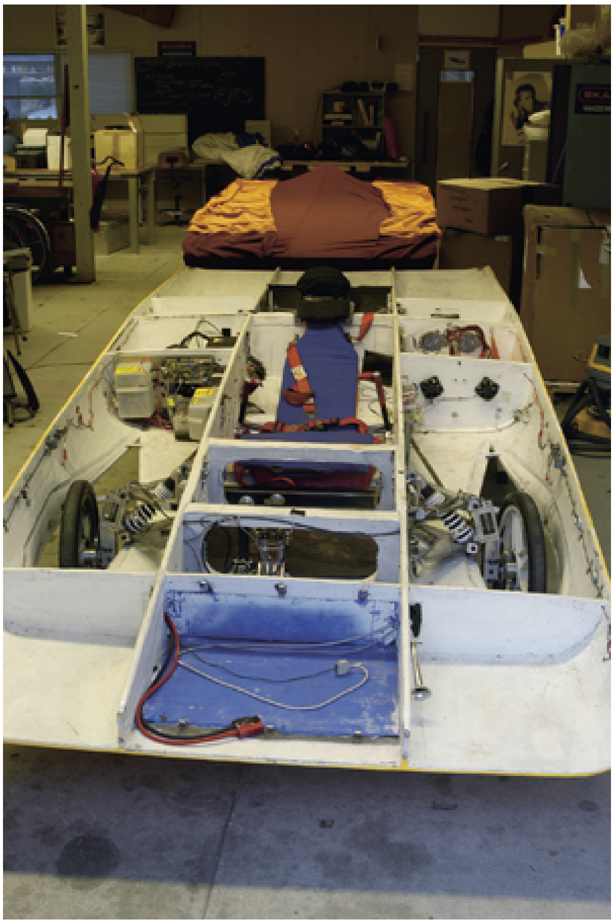


This top view of the windtunnel tests of Nuna II shows that laminar flow extends as far as the cockpit canopy.



The front Nuna II was redesigned as to have an even lower drag factor than its predecessor. During the windtunnel tests Nuna II proved to have a Cw-value of no more than 0.09.

This seems a lot, but both of Nuna II's front wheels have a streamlined housing. Thus the space is limited and a turning circle of 16 metres is quite a challenge. The brakes were also tested. Although the Nuna II's regenerative braking is good, that is not enough for an emergency stop. The front wheels are therefore fitted with disk brakes and the back wheel with a cantilever brake. During tests on the Hidden Valley circuit in Darwin Nuna II reached speeds of over 100 km/h on the straights, whereupon the drivers had to brake sharply going into the bends.



Apart from the drag factor, weight also plays an imported role when it comes to efficiency. So the team decided to integrate the bodywork and chassis into a self-supporting construction, using strategically located reinforcements.

Ventilation

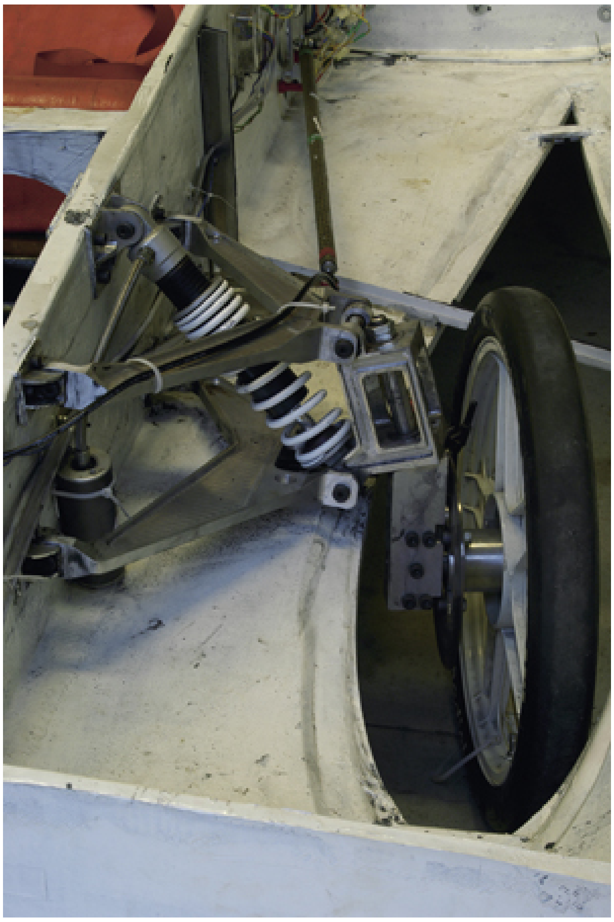
Once Nuna II had passed the roadworthiness test, the team could take it out on the public road for trial. The road they used was the Arnhem Highway, a motorway that runs from just outside Darwin into the heart of the Kakadu National Park. During the tests, the temperatures in the car rose sharply, and not only in the cockpit. The temperature of some important electronic components climbed to 80 °C, almost double the temperature they were designed for. To prevent overheating, a cooling system had to be designed and installed on the spot. Holes were drilled in the bodywork for ventilators and cables to admit air to cool the electronic equipment and the batteries. The drivers just had to put up with the heat.

Olsthoorn: 'So long as you were driving it was bearable. But as soon as you stopped you had to jump out of the car, otherwise you would bake in it.'

Before the race itself there was a qualification heat, a 'flying lap' on the test circuit at Hidden Valley, to determine the starting positions. Nuna II's time meant it started in tenth place. Not a brilliant start, but as one of the team members put it: Nuna II is not built for a racing circuit but for a journey of 3000 kilometres over open roads. This was immediately apparent on the first day of the race. Although it started in tenth position, after four hours Nuna II was already in the lead, a position it was never to surrender.

Olsthoorn was driving as the last challenger was overtaken. 'It was an impressive moment', he remembers. 'The MIT vehicle was moving pretty fast, at over 100 km/h. I passed it at more than 130 km/h. It was a fantastic feeling at that moment, to see all the effort of the previous eight months being rewarded.'

The 1500-plus kilometres to Alice Springs, in the heart of Australia, were covered in two days. By then the lead over the two nearest challengers, Aurora and MIT, had widened to more than half an hour. In the two days that followed the lead was extended further and in the middle of the afternoon on Wednesday 22 October Nuna II arrived in Adelaide. The Aurora, which was second, did not reach Adelaide on the Wednesday, only arriving in the early hours of Thursday morning.



Formula I

The only setback, although to call it a setback is an exaggeration, occurred on the third day of the race when the car had two punctures in quick succession. The first was probably caused by a pebble picked up in the car park. This would normally not have been a problem, but, says Olsthoorn, ‘we had pumped up the tyres early in the morning when it was still quite cool. The temperature rose quite sharply during the day, so that the tyre pressure was probably too high.’

Another factor that contributed to the punctures was that throughout the day there was a fairly strong side wind, which meant the drivers had to pull strongly on the steering wheel to counter it. The Nuna II has 16-inch tyres, the size of the tyres on a motor scooter, which are made specially for solar cars. They have a low rolling resistance, but that also means they are not very resilient to wear.

Hinderdael: ‘After the tests on the Arnhem Highway we already suspected that the tyres could be a problem. We practised hard at changing tyres quickly, as they do in Formula I racing. It worked like a dream. We could change a tyre in four minutes. The Aurora team took at least seven minutes.’

Tactics

Apart from the two punctures the race actually went pretty smoothly. ‘With hindsight anyway,’ says team leader Diederik Kinds, ‘but after encountering so many problems in the run up to the race, sitting in the pursuit car you are still worried. You have the feeling that every noise and every unexpected movement could herald a disaster.’

The race itself also requires a lot of effort, says Wubbo Ockels: ‘You receive an enormous amount of data, about the weather, about the road and about the vehicle, and you are constantly using that data to make decisions which can seriously affect the course of the race.’

However great the tension during the race, the delight at the finish, a few kilometres outside Adelaide, was even greater.

‘You are sitting there waiting to see the finishing line,’ says Kinds, who was in the pursuit car. ‘You know it has to be close, but you say nothing. Then suddenly you see a blaze of orange at the side of the road, with helicopters overhead and the media cars and you know you’ve done it. That you have succeeded in driving across Australia in four days using only the sun as fuel.’

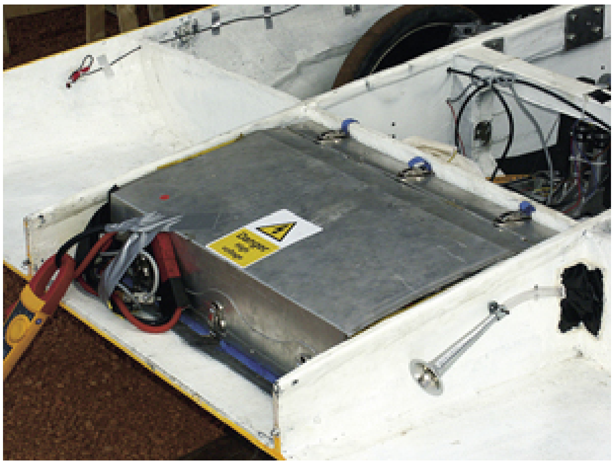
Winning the race is one thing, but more important, says Kinds, is that you have shown that there are alternatives to fossil fuels in transport. In other words, that sustainable transport based on solar energy is not science fiction, but a realistic option. For many team members that was one of the main reasons for taking part. However, a lot of development work still needs to be done to realise that option. We haven’t had the last Solar Challenge yet.

‘We will be taking part again in 2005’, says Ockels. ‘Our ambition for Nuna III is to develop more of the parts ourselves. At the same time we want to challenge the car industry to use its energy and creativity to develop vehicles that run on solar energy. They should show as much commitment to racing on solar energy as they currently display to Formula I racing.’

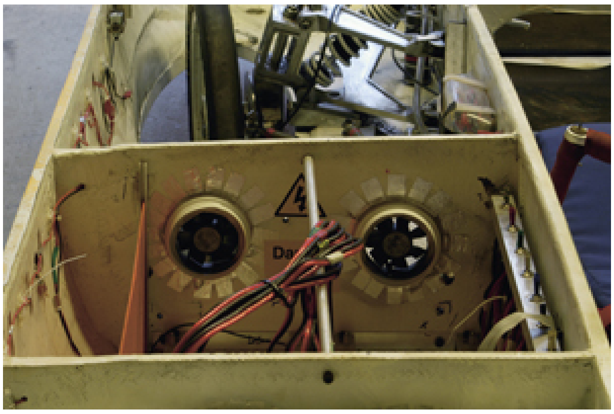
For further information about this article, please contact Prof. Dr Wubbo J. Ockels,

The suspension triangles were designed and made by team members in the workshops of the Faculty of Aeronautical Engineering at Delft University.

Two Delft winners of the Australian World Solar Challenge outside the team's workshop at Delft University of Technology. There is clearly a difference between the first (right, winner in 2001) and the second generation.



The all important energy box, containing the lithium-ion batteries. Over 5kWh was stored at 180 volts. Of course a proper horn was also part the standard equipment as the race took place on the public roads in Australia.



Two electric fans were mounted to keep the electronic equipment below 50 °C. On the right of the picture some of the 28 switches the pilot had to operate.

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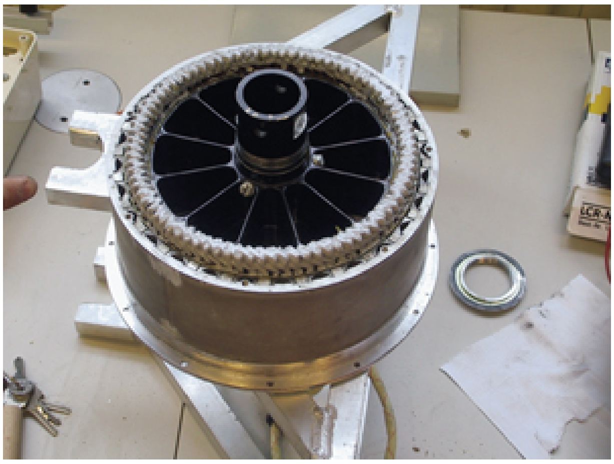
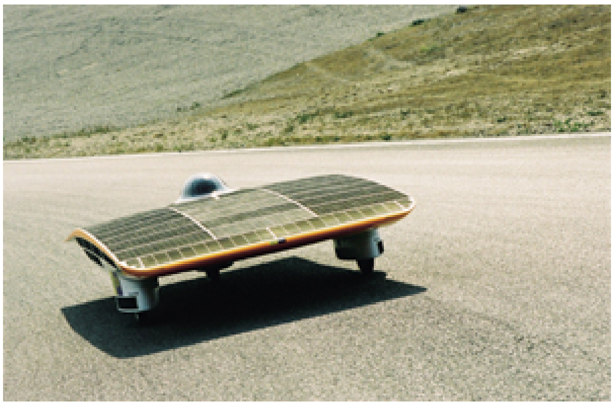
See also www.wsc.org.au

Nuna II is driven by the rear wheel that has an incorporated electric motor.



The (fixed) inner ring of the Swiss brushless electric motor with coils and the outer ring with permanent magnets.



The first speed tests were carried out at the Zandvoort racing track on the North Sea coast, some 30 kilometers from Amsterdam. Top speed: 175 km/h.

Twenty tents in the desert night. They were provided to the team by Ten Cate Fibres, one of the sponsers.

Nuna II asleep under the Dutch national flag in its own tent.

Preparing for the start on the last day of the race

The Nuna II was the first to cross the finish line in Adelaine after only 30 hours and 54 minuts, averaging a speed of more than 97 km/h.

SOME OF THE COMPETITORS

AOYAMA GAKUM UNIVERSITY (JAPAN)

PRINCIPIA COLLEGE SOLAR TEAM (USA)

SUNGROPER (AUSTRALIA)

FORMOSUM (TAIWAN)

MIT SOLAR ELECTRIC VEHICLE TEAM (USA)

QUEENS UNIVERSITY (CANADA)

HELIODET (GERMANY)

AURORA VEHICLE ASSOCIATION (AUSTRALIA)

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