Solar-powered composite car designed to win

Three for three in Australia's famed solar car race, university students from The Netherlands take this redesigned <420-lb carbon composite vehicle Down Under for number four.

Design Results:

- *Tighter-weave carbon fiber fabric optimizes stiffness in the thin-walled aerodynamic body.*
- *New, vacuum-infusable thermosetting urethane matrix with a T_g that yields epoxy-like performance in extremely hot weather.*
- *Integral C-stiffeners and vacuum infusion processing enable production of semimonocoque composite chassis.*

NUNA4 Solar Racer

Total weight: 190 kg/420 lb (excluding driver)

Driver weight minimum: 80 kg/176 lb

Top speed: 145 kmh/90 mph

Solar array: 2,318 Gallium-Arsenide triple-junction solar cells

On Oct. 21, 2007, 46 teams from 21 countries will race custom-built cars from Darwin, at Australia's northernmost point, a distance of 3,000 km/1,864 miles across the continent to the southern port city of Adelaide. Although the high-profile event will be replete with corporate sponsors and plenty of media hoopla, there will be no roaring engines, squealing tires or scent of high-test fuel. Competitors who cross the finish line in this event will do so with a quiet whirr, powered entirely by the hot Australian sun. Much of the media attention in the 20th anniversary running of the biennial Panasonic World Solar Challenge will be focused on the *Nuna4* Nuon Solar Team, whose solar-powered electric cars have swept the past three Challenges (*Nuna3* set an average speed record of 103 kmh/64 mph). Sponsored by Nuon Corp. (Amsterdam, The Netherlands) in conjunction with Delft University of Technology, KLM Royal Dutch Airlines, financial backer ABN Amro (Amsterdam, The Netherlands) and more than 30 suppliers, the team of 11 Delft University students will defend Nuon's World Solar Challenge title with the fourth in its series of challengers, *Nuna4*.

Capturing sun on the run

The *Nuna* designs all have been carbon composites, rather than aluminum, a common material of construction for most Challenge contestants. The Nuon Solar Team's Hjalmar Van Raemdonck, responsible for structural design, says he prefers carbon composites not only for the weight advantages — *Nuna4*, sans driver, weighs less than 190 kg/420 lb — but also for their higher specific strength and specific stiffness compared to aluminum as well as better fatigue properties and the ability to drastically reduce part count.

Unlike an aluminum construction, which would require multiple aluminum parts that must be fastened together, the *Nuna4* body is a semimonocoque design. Its aircraft wing-like shape is subject to only one-sixth the aerodynamic drag encountered by a typical

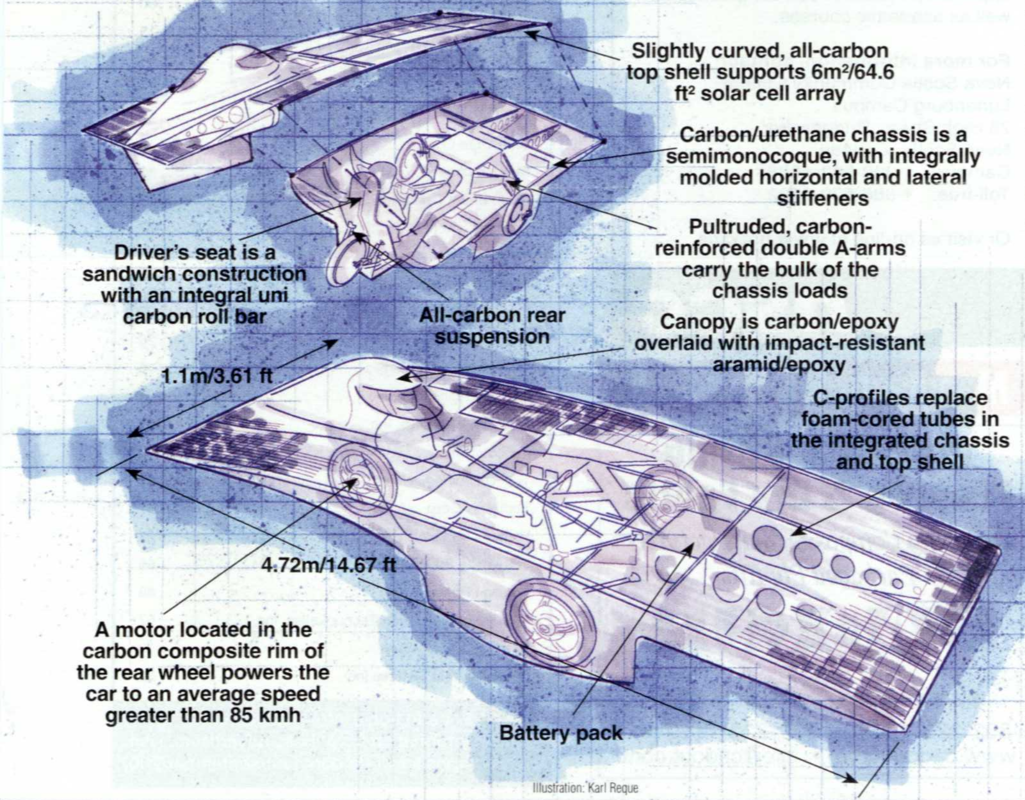
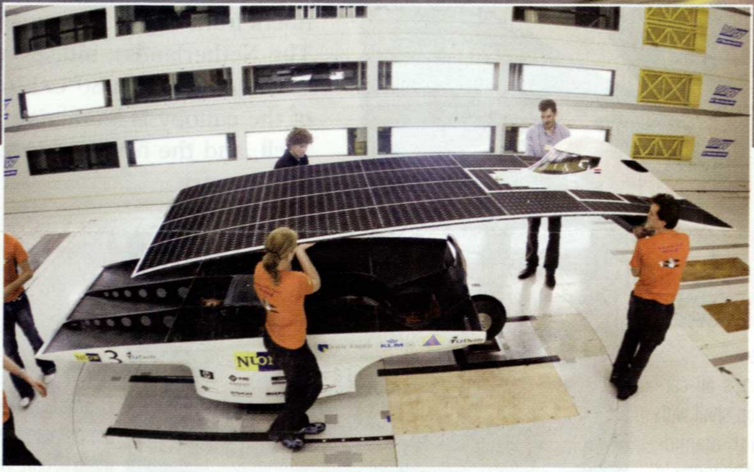


Illustration: Karl Reque

The solar-powered *Nuna4* on the road, with a top speed of 145 kph/90 mph.

Source: Nuon Solar Team



Source: Nuon Solar Team

Student members the Nuon Solar Team at Delft University of Technology lift the top shell, with pilot canopy and solar array, onto the car's integrated chassis.

production automobile. Its almost flat top provides a maximum horizontal surface for the solar cells that produce the energy necessary to drive an electric motor mounted in the rim of the rear wheel. The energy the lightweight *Nuna4* needs to run 100 kmh/62 mph is equivalent to that needed by a vacuum cleaner. When the solar panels generate more electricity than needed, the excess is stored in rechargeable batteries, which keep *Nuna4* going in cloudy conditions.

Redesigning for new rules

For the 2007 race, however, the Nuon Solar Team faced several design challenges occasioned by changes in race regulations. Most significant was a new rule that limits the surface area of each car's solar array to a maximum of 6m^2/64.6 ft^2. Further, the team had to factor in two new safety requirements. The first called for an upright, 27° seating angle (inclined positions were ruled out because they limited driver visibility and increased the risk of fatigue). The second requirement was a roll bar to protect the pilot and cockpit in case of a rollover.

In its design calculations, therefore, the team had to consider several factors: the aerodynamic loads on the body of the car, the maximum allowable deflection to maintain its aerodynamic shape, a possible 4G impact load on the roll bar, 4G suspension loads on the chassis, buckling of the thin-walled shell, the mass of the pilot (minimum 80 kg/176 lb) and the batteries (30 kg/66 lb), and the handling of the *Nuna4* with pilot aboard. For design analysis, Raemdonck selected Patran/Nastran Finite Element Method (FEM) software from MSC.Software (Santa Ana, Calif.) to calculate the stiffness and strength of the construction, and Kolibri software from Lightweight Structures BV (Delft, The Netherlands) for other calculations.

"Stiffness was especially important in the top shell, due to the solar panels," Raemdonck says. Although it is almost flat, the shell has a slight curve, orienting the 2,318 solar cells imbedded in the solar panels toward the sun.

An important change from the *Nuna3* composite design was the use in the body/chassis and seat structures of a carbon fiber fabric with a tighter 3K weave, supplied by Ten Cate Advanced Composites (Nijverdal, The Netherlands). While 3K fiber also was used in *Nuna3*, Raemdonck says the fabric used for *Nuna4* has "higher g/m^2 with better engineering properties."

The upright seating mandate, Raemdonck says, presented new design opportunities for *Nuna4*. "Due to the 27° rule, we based the design on the pilot's position. Everything around the pilot is very stiff and strong. The rear suspension sits right behind the pilot, the front suspension just in front of his feet" (see illustration, p. 70). The rear suspension trailing arms were vacuum infused by the *Nuna4* team from carbon fiber and Turane urethane resin, processed at 80°C/176°F. Turane is a thermosetting urethane from a new resin family produced by DSM Composite Resins AG (Schaffhausen, Switzerland). The thermal resistance of the Turane resin used for *Nuna4* was adjusted for Australia's ambient temperature conditions of -20°C to 60°C (-4°F to 140°F). Most important for the *Nuna4* team, the urethane maintains dimensional stability at relatively high temperatures and meets the Solar Challenge environmental requirement of a glass transition (T_g) temperature of 95°C to 150°C (203°F to 302°F) — the approximate midpoint of the temperature range over which the hard, cured composite begins to soften. According to DSM Composite Resins expertise manager Ron Verleg, the urethane was easy to process by vacuum infusion but provided the compatibility with carbon fibers and structural performance typically expected from an epoxy.

For the front suspension system, the team assembled the double A-arms, which carry the greatest chassis loads, from carbon tubes pultruded by Prince Fibre Tech BV (Dronten,

Above:
The car's all-carbon top shell with integral aramid-skinned canopy is removed from the curing oven.

Source: Nuon Solar Team

C-profile stiffeners are prepared for integral cure with the 0.9-mm/0.035-inch thick lower chassis base plate.

The Netherlands). Air-sprung carbon shock absorbers, which are combined vibration dampers and springs, were purchased from DT Swiss AG (Biel, Switzerland).

While the three-wheeler's front wheels are aluminum, the rim of the rear wheel, where the motor is located, is a composite reinforced with carbon and aramid fiber. Even the steering wheel is a composite, fabricated from the carbon/urethane by vacuum infusion and cured at 80°C/176°F.

The *Nuna4* roll bar was made from unidirectional carbon tape and integrally molded into the driver's seat, which is a structural sandwich construction of woven carbon skins and Corecell structural foam core supplied by Gurit (Magog, Quebec, Canada). Raemdonck says the Corecell foam is of higher density (70 kg/m^3 or 4.4 lb/ft^3) than the Alcan Airex AG (Sins, Switzerland) Herex foam core (60 kg/m^3 or 3.7 lb/ft^3) used for *Nuna3*. "The denser foam absorbs less resin, so the total mass of the Corecell core after infusion is lower than that of Herex after infusion," Raemdonck explains.

Infusing the fewest parts

To build the semimonocoque chassis, the lower shell and its longitudinal stiffeners were infused as one piece; the top shell also was infused as one piece except for the rear wheel enclosure, which extends beneath it, and the canopy. To maximize impact resistance of the canopy and wheel housings, the team used one layer of carbon and two layers of more flexible Twaron 170g and 250g aramid fibers from Teijin Twaron BV (Arnhem, The Netherlands), infused with Turane resin and cured at 80°C/176°F. The rear of the canopy is laminated into the top shell, and the front is hinged to permit driver entry.

The carbon/urethane chassis is self-supporting, with a 0.9-mm/0.035-inch thick base plate strengthened with integrally molded horizontal and lateral profile stiffeners. To ensure stiffness, a majority of the fibers were oriented in the longitudinal direction, and extra unidirectional carbon tape was added to the nose.

In another significant design upgrade, thin-walled (0.9 mm/0.035 inch) C-profile stiffeners were integrated into the chassis and the top shell, replacing heavier foam-filled tubes used in previous *Nuna* designs. "At the start of the design, I was thinking about methods to reduce the foam coring in the construction, especially in the top shell," says Raemdonck. Early on, he considered tubular structures made with a silicon core or with Aquacore, a soluble "lost-core" material from Advanced Ceramics Research (Tucson, Ariz.), before settling on the C-profile stiffeners, built using tooling principles and a production technique developed by Lightweight Structures BV. Raemdonck explains that the advantage of C-profiles is they provide the necessary strength without the additional weight of a core. The profiles are modified with circular cutouts after cure to further reduce weight.

The *Nuna4* team made the chassis and top shell and other large sections at a production hall on the university campus while the steering wheel and other smaller composite parts were fabricated in the composites lab of the university's aerospace facility.

Winning the alternative energy race?

Raemdonck expects the *Nuna4* to go on tour for its sponsors after the race and "after that, it will be used as inspiration for the *Nuna5*." He says he cannot predict the life cycle for *Nuna4*, but he says *Nuna3* has been on tour since its win, and *Nuna2* has already logged about 30,000 km/18,641 miles on various tours.

Solar power is an inexpensive, sustainable energy source increasingly used for residential heating and electrical supply. It has been proven as a source for vehicular power in past races in Australia and other venues. The question is whether it can win another race — the one against other forms of alternative energy developed to replace petroleum as a cost-effective means of powering land transportation. The answer is unclear, but Raemdonck notes that solar powered vehicles aren't just pie-in-the-sky: the Venturi *Astrolab* hybrid electro-solar car, built by Venturi in Monaco, has become the first high-performance solar vehicle to be commercialized on Earth — it was preceded by those two solar-powered rovers now exploring Mars. Certainly it's a technology worth watching. HPC

— Donna K. Dawson, Senior Writer

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