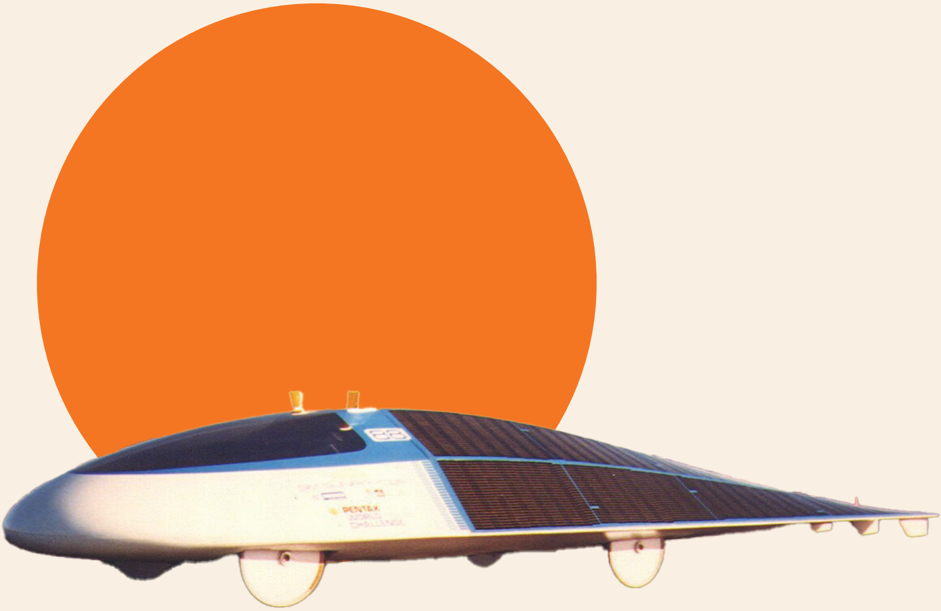

SunRaycer

History & Technical Data

Caltech

EAS Division of Engineering and Applied Science

SAE Southern California
An SAE International Section

history of the SunRaycer

The SunRaycer came into being thanks to an unusual combination of unlikely events. The saga begins with Hans Tholstrup, an Australian adventurer whose love for nature combined with his passion for adventure. Motivated by climate change, he and engineer Larry Perkins drove a solar-powered vehicle across the Australian continent in 1983 – from Perth in the west to Sydney in the east. That experience motivated Tholstrup to think bigger and challenge the world to the first transcontinental solar race. Forty-four pages of rules were assembled, and sponsorship was obtained.

In late 1986, a copy of these rules landed on the desk of GM's CEO, Roger Smith, who then sent them on to the newly-acquired Hughes Aircraft Company, where they caught the attention of Vice President Howard Wilson. Wilson reasoned that entering the "World Solar Challenge" race could provide valuable public exposure for GM while helping link Hughes with the automotive world. One challenge stood out: The race was set to start on November 1, 1987, less than ten months away.

Wilson brought up the matter with Ed Ellion (Caltech PhD '53), Director of Technology at Hughes. Ellion, in turn, suggested that Wilson contact Paul MacCready (Caltech PhD '52), a former classmate of his and founder/CEO of AeroVironment (AV). Wilson did just that, and after initial meetings, AV enthusiastically took on the job – to design and fabricate the world's fastest solar-powered vehicle.

A year and a half earlier, AV had taken on a special project for the National Air and Space Museum – the design and construction of a flying half-scale replica of a Quetzalcoatlus Northropi, a giant prehistoric pterodactyl with a wingspan in excess of 30 feet. Because of this project, Alan Cocconi (Caltech BS '80) became a consultant to AV - to execute flight controls associated with both the head and wings. Thanks in part to the pterodactyl project, one of the country's most talented power electronic engineers had connected with AV.

At the outset, Alec Brooks (Caltech PhD '81) took leadership of the SunRaycer effort. One of the first tasks was to determine the vehicle configuration and basic parameters. From this effort, it was understood that a curved, integrated solar panel would provide a superior result compared to the conventional flat panel array, which could be tilted for optimal sun. The curved, integrated approach would significantly reduce aerodynamic drag, but it would also reduce the solar panel's electrical output. Analysis indicated that the trade could provide a net gain.

The curved array, however, posed a technical problem: different parts of the array would have different illumination and thereby have different electrical outputs. Based on previous experience with the design of solar inverters, Cocconi was able to quickly design and fabricate a so-called "power tracker" – an electronic regulator which would automatically adjust parameters such that the maximum possible power would be extracted from a given solar panel segment. Test results demonstrated the needed high energy efficiency, accurate power tracking, and low weight (see Technical Data). Twelve panel segments and twelve corresponding power trackers were used. GM funded the project through Hughes, and AV went ahead with the design of the SunRaycer. A quarter-scale model of the SunRaycer was tested in the Caltech Merrill Wind Tunnel for various parameters, including cross-wind stability.

In addition to the Power Trackers, Cocconi designed and built the motor-drive inverter and the associated driving controls. Hughes provided the space-grade high-efficiency gallium arsenide photovoltaic cells, which they mounted, interconnected, and tested. GM designed and fabricated the 5 kg, 7 kW (peak) permanent magnet electric motor. The key element in the motor was the high-energy product Magnequench magnet material – recently developed by GM. Construction and rigorous testing of the SunRaycer were completed in early October 1987.

Thanks to a data acquisition and telemetry system developed by John Gord (Caltech BS ’74), the SunRaycer was able to transmit system data to a follow vehicle. In real time, parameters such as battery cell voltages, vehicle speed, and array segment currents could be viewed and analyzed by race strategists armed with computer support so that driving speeds could be optimized for prevailing conditions, and potential problems could be solved before they became real.

On November 1, 1987, at 9:00 AM, the 1950-mile race commenced at Darwin in northern Australia. The SunRaycer sprinted well ahead of the other twenty-four solar vehicles. After less than six racing days on Australia’s Stuart Highway and a corrected time of 44 hours and 54 minutes, the SunRaycer crossed the Adelaide finish line in Southern Australia. Two days later, the second-place vehicle, Ford’s Sunchaser, crossed with a corrected race time of 67 hours and 32 minutes. It was a landslide victory for the SunRaycer.

technical data:

The SunRaycer structure consisted of a welded aluminum space frame, a suspension, body panels, a propulsion system, and an instrumentation and telemetry system. In turn, the propulsion system consisted of a twelve-segment gallium arsenide solar array, twelve electronic power trackers, a silver-zinc energy storage battery, a motor inverter, an analog controller, an exterior permanent magnet electric motor, and a cog-belt reduction drive (see details below). The vehicle could be driven in any of three modes: mode 1 where the accelerator pedal controlled motor torque (including regenerative braking), mode 2 (cruise control), where a preset speed was maintained, and mode 3, where a preset battery charge or discharge current was maintained.

Array

Material	Gallium arsenide
Number of cells	8,800
Number of segments	12
Area (total)	8 m^2
Rated efficiency	20%
Max power output	1,500 W
Open circuit voltage	160 V

Power Trackers

Number (one per array segment)	12
Power topology	buck
Max. input voltage	250 V
Max. output current	2 A
Efficiency (nominal operating point)	98.4% (at 100 W)
Weight	250 g
Tracking technique	Inject array voltage ripple; control array V for zero power ripple

Battery

Type	Silver zinc
Number of cells	68
Cell capacity	30 Ah
Energy	3 kWh
Full charge OCV	126 V
Nominal voltage	90 V
Weight	30 kg

Aux Power System

Type	DC to DC Converter (Vicore)
Output voltage	12 V, regulated (for lights and instrumentation)
Max. output current	15 A

Inverter

Topology and switching devices	Three-phase, voltage-fed, MOSFET
Number of switches in parallel	10 (60 total)
Switching frequency	20 kHz
Max. input voltage	200 V
Max. peak phase current	100 A
Rated max. power	7 kW
Efficiency	98% (nominal operating point)
Cooling	Ram air
Control	**Inner loop:** current mode **Outer loop:** selectable: accel. pedal, speed, or batt. curr. **Limits**: over-voltage, under voltage, over temp.

Motor

Type	6-pole, exterior permanent magnet
Magnet material	Magnequench (GM development), 14.3 MGOe min., Tc = 320 C
Max. torque	25 Nm
Max. speed	5,000 rpm
Nominal operating point	3225 rpm, 3 Nm, 1 kW
Efficiency (nominal operating point)	92%
Cooling	Ram air
Position encoder	Optical, 8 bits (256/rev, gray code)
Weight	5.0 kg

Drive

Description	Cog-belt drive to single rear wheel
Belt ratio	4:1
Wheel	BMX (46 cm diameter, 0.8% rolling resistance coefficient))
Efficiency (nominal operating point)	Approx. 95%

Suspension

Front	McPherson strut
Rear	Trailing arm

Steering	Rack and pinion
Driver Inputs	Accel. pedal, brake pedal, and mode select
Driver Display	Vehicle speed, bus voltage, inverter input current, battery voltage, battery current, array segment voltage (12), array segment temps (10 selectable), motor temp., battery temp.
Telemetry	Operating parameters were transmitted to a follow vehicle: speed, bus voltage, array segment voltages, battery cell voltages, battery current, array segment temps., inverter temp., motor temp., battery temp.

Vehicle

Outline dimensions	6.0 m long x 2.0 m wide x 1.0 m high
Drag coefficient	0.13
Frontal area	1.5 m^2
Structure	Aluminum space frame plus Kevlar/Nomex body panels
Frame weight	6.8 kg
Vehicle weight (total)	177 kg
Max. speed	68 mph
Zero to 60 mph time	20 sec.
Energy efficiency	14.9 Wh/km (23.8 Wh/mi.)