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# INNOVATION IN SOLAR VEHICLES: FROM THE IDEA TO THE PROTOTYPE IN LESS THAN 24 MONTHS

***Abstract:*** *The article aims to describe the integrated path used for the conceptual, functional and constructive design of an exclusive solar vehicle. The project was based on the massive implementation of concurrent engineering and quality tools, rarely used in such an integrated way. New and attractive design, 3D CAD modelling, details design, structural and fluid dynamic validations, in-scale rapid prototyping, functional tests, multi-objective optimization, parts manufacturing and assembly. Thanks to this approach, the solar prototype presents high technological contents, especially in terms of materials, structures and processes, together with their optimizations. Furthermore, large CNC-machined multi-material molds, hybrid manufacturing solutions: everything was used to speed up phases permitting to move from the initial idea to the final prototype in 24 months. Since June 2018, the solar vehicle is on the road, transporting 4 people, weighing less than 300kg, reaching speeds of 120km/h and able to run hundreds of km without fuel.*

***Keywords:*** *Solar Vehicles, Design for Quality, Process Quality, TQM, QFD, Innovation*

## 1. Introduction

This short article summarizes the incredible adventure of a group of researchers that led to the design and construction of one of the few multi-vehicle solar vehicles in the world, and its use to cross a large part of the United States.

Everything started from the sporting passion for automotive competitions and from the previous experience in the field of solar vehicles, which led to the creation of a solar single-seater in recent years. With this vehicle we took part in several races on different continents bringing back valuable successes. However, the category of single-seater solar vehicles did not seem to represent a real technological challenge as it appeared to be the category of multi-passenger vehicles. Known under the name of '*cruiser*' car, this relatively recent category in the racing scene obliges designers to face particularly complex technical problems, linked to the specific needs of solar mobility.

Solar cars have to be imagined by the designers around the fundamental concept of energy efficiency. This condition requires important technical choices that, combined with the race regulation requirements, lead to exclusive and very innovative prototypes.

Besides, everything was made possible only thanks to the use of concurrent engineering and its design tools, within a more general

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approach to Total Quality Management (TQM) (*Fragassa et al. 2014*).

## 2. Materials and Methods

Specifically, the following phases and tasks were considered:

1. Aesthetic Design
   - International design competition
   - Comparison of style proposals
   - Definition of the final design
   - Realization of sketches
   - Realization of 3D renderings (Fig.1)
2. Functional Design
   - Conceptual design of solutions
   - Quality Function Deployment
   - Rapid prototypes (in SLS, scale 2:3)
   - Wind Gallery investigation
   - Dedicated CFD algorithms
   - Open-source platform for multi-objective optimization
3. Construction Design
   - Advanced modeling of composites
   - 3D detailed design of parts
   - FEM and SPH in CAE optimization
   - Real dimension prototypes for functional tests (in ABS and metals)
4. Material Design
   - Massive use of carbon fiber (> 90%)
   - Use of titanium fiber reinforcements
   - Use of hybrid composites (eg basalt)
   - Use of natural / low VOC resins
5. Process Design
   - Merging hybrid cutting processes and rapid prototyping techniques
   - Merging hybrid cutting processes and autoclave forming
   - Communication protocols (from CAD to CAM) for hybrid processes
   - Realization of molds for car body (N. 5, in resin)
   - Realization of molds for part and components (N. 53, in composites, aluminum and MDF)
6. Quality Design
   - Laser scanning for quality control
   - Structural parts (frame, leaf springs, joints) and non-structural (brakes, wheels, steering) manufacturing
7. Experiment Design
   - Tests in supervised conditions (inside an airport)
   - Tests on the roads
   - Tests during the competition (Fig.2)

**Figure 1.** Style proposals from the design competition (by Filip Relic, U. Arts Belgrade)

## 3. Result

The result of this process is a 4-seater, electric solar-powered vehicle. Size 4.6x1.8x1.2m; empty mass (including batteries) of 230 kg and a maximum of 600 kg. Main structure and components in carbon fiber reinforced polymers (CFRPs), with some parts in kevlar, titanium and ergal. Front surface of 1.60 $m^2$ with Cx of 0.20. Maximum expected speed 100 km/h, average consumption of 21 Wh/km (at 55 km/h), range of about 750 km (at 55 km/h). Photovoltaic panel in monocrystalline silicon, 5 $m^2$ with 326 SunPower cells, maximum efficiency 24% (at 25 °C) and maximum panel power of 1.1kW. Converter with 98% efficiency. Battery pack: 83 kg positioned in the central tunnel, 1344 Samsung lithium ion cells with a nominal capacity of 3.4 Ah; rated voltage 48V, intensity 331.2 Ah, total energy 16.1 kWh; 2688 temperature sensors. Two synchronous motors with permanent surface magnets on the rear wheels: external rotor coupled directly to the wheel, stator on the structure. Each 11kg motor has a nominal power of 1300 W and a maximum of 3000 W (nominal torque of 35Nm and a maximum of 125 Nm); expected efficiency 97%.

**Figure 2.** Solar car during manufacturing, assembly and winner at its first race.

## 4. Discussion and Conclusion

- build a four-wheeled vehicle, quadricycle
- minimize the overall dimensions of spacemaximize the space where to house the solar panels
- carry 4 passengers safely
- balance weights and vehicle dynamicsprovide adequate space for vehicle components such as: engines, suspensions
- provide adequate space for electrical components such as: engines, suspensions,guarantee fast access systems for access in case of maintenance
- optimize the aerodynamic profile by reducing air resistanceguarantee a phenomenon of downforce in order to reduce the rolling resistance
- correctly convey part of the air for cooling and ventilation
- ensuring the internal liveability of the spaces and the installation of auxiliary devices
- insert elements such as doors, air vents, lights, arrows, license plate in line with the standardsuse shapes that can be built with available materials and technologies
- provide for the possibility of registration and registration of the vehicle

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