29 Jan 1993

# Application of Sunlight Mapping in Solar Car Design

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Physics, Computer Science, Electrical Eng., Electrical Eng.

The design of a solar car is a combination of trade-offs between the mechanical, aerodynamic, and photovoltaic systems. The mechanical and aerodynamic systems can be computationally modeled very well using commercial software. Clouds prevent the photovoltaic system from being modeled as well. This research explores a new way to accurately simulate almost every array configuration imaginable. Using this method, quantitative simulations are produced.

## INTRODUCTION

### Solar Car project at UMR

The University of Missouri - Rolla has been accepted to compete in two intercontinental solar car races, Sunrayce '93 and the World Solar Challenge. Sunrayce '93 is an 1100 mile biennial intercollegiate competition from Texas to Minnesota. The World Solar Challenge is an 1800 mile international solar car competition from Darwin to Adelaide.

The Solar Car Team consists of 50 students from Aerospace, Mechanical, and Electrical Engineering, as well as students from Computer Science, Physics, and Engineering Management. The car is being constructed in several labs on and off campus. The chassis of the car is being constructed in G-3 Basic Engineering, the aerodynamic shell is being constructed in the Old Miner Recreations Building, and the solar cells are being tested in the Engineering Research Laboratories (ERL).

### Examining the trade-offs

The essence of a solar race car is the same as any other race; to go as fast as possible. A competitive solar car should be designed with an understanding of the particular race course and weather conditions into account. A 2000 mile transcontinental solar car race across relatively flat ground requires that the car be light and aerodynamic. A short 100-200 mile race across very hilly terrain would place importance on weight and power production. By looking at some of the previous solar car designs, one might understand the trade-off each of the teams made.

Each day, Sunrayce begins at 7 am with a two hour charging period. The teams race between 100 and 200 miles to a collective overnight camp. After the cars reach the overnight camp they are allowed to charge until 8 pm. In comparison, in the Australian race each team travel as far as it can from 9 am till 5 pm. This results in a race pack which is spread out over hundred, if not thousands, of miles.

For example, in 1990 the University of Michigan won the GM Sunrayce (from Florida to Michigan) but placed third in the World Solar Challenge (behind two smaller and more aerodynamic vehicles.) Western Washington University placed second in the GM Sunrayce but fifth in the World Solar Challenge. Both teams were excellent and well prepared, but their cars were designed for the US race, not the Australian race.

To examine the trade-offs of a particular design the students must realize the effects a given design modification will have. For example, should the array be larger (more solar cells would fit) with a higher aerodynamic drag (from having a larger car), or should the car be smaller to have a lower aerodynamic drag with less power. The answer will be, "whichever makes the car go the fastest for the expected race conditions." That design will be found by modeling the various systems.

### Systems modeling to optimize performance

The mechanical systems are typically modeled using finite element analysis (FEA) to minimize the vehicle weight while insuring structural integrity. There are several software packages available to perform an FEA on DOS, UNIX, or VMS. Loads are applied to the proposed structure and the stresses through the elements of the structure (defined by the user) are calculated and compared to the known mechanical properties. Then, if any of the element stresses exceed the design stresses, the user would modify the structure and run the analysis again.

The aerodynamic systems (shell, wheels, cowlings, etc.) are simulated using a computational fluid dynamics (CFD) analysis to minimize the aerodynamic drag. The aerodynamic shape is defined and various wind speeds and direction can be applied to calculate the drag force, coefficient of drag, or the pressure distribution.

The solar array, a collection of photovoltaic cells, can be numerically approximated if clear skies are assumed. Since there has not yet been a rain-free trans-continental solar car race, understanding the effects of clouds would be advantageous. Clouds scatter the light in a way which is difficult to model because the cloud cover can vary so greatly. A uniform cloud cover will simply make the sunlight less intense and more diffuse. Scattered clouds, if not directly blocking the sun, can actually increase the power collected due to the light they reflect. The water in the clouds also has spectral absorption properties which will affect the spectrum of light at the cell. These factors hinder the development of an accurate array power model.

## SOLAR ARRAY POWER SIMULATION

### Goals

The goal of this research is to develop a tool for computationally simulating various solar arrays based upon actual data. The analysis program should accept multi-faceted arrays and should return the solar array power for a proposed array at a given time of a given day. An application of the method would require that data be taken for several sunny days and several cloudy days, with clouds of varying intensity. The data from those days with weather conditions similar to those expected on the race would be used in the analysis.

Simulation method

The best way to find the power output of a solar cell facing a certain direction is to actually measure the power output of a solar cell facing that direction. If we could measure the power output of a solar cell at all directions, we could then simulate any array configuration imaginable. A two-axis spinning platform with a solar cell attached to the platform could scan the sky and record the power output from the cell at all angles.

## TRACKING PLATFORM

Two-axis platform

The platform consists of two moving parts, the base and the arm. The base is a "lazy Susan" chair swivel driven by the stationary motor through a 1:100 gear ratio. The gear attached to the swivel base was warped slightly and required a tensioner to push the base motor against the gear. Two upright angle brackets were bolted to the base and a rod was attached to the top of the angle brackets as to rotate freely. The arm consisted of another angle bracket, bent into a J shape, which was connected to the rod. A gear placed on the end of the rod contacted the gear on the arm motor (mounted to the upright brackets.)

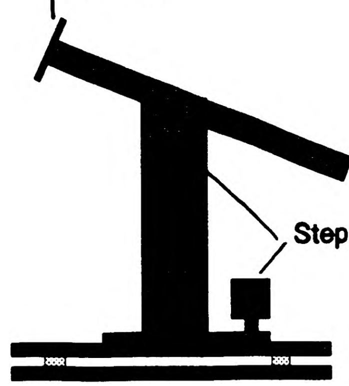


**Figure 1** Tracking platform

Both motors are 1.8°/step stepper motors salvaged from scrap disk drives. They have four windings which are energized in a specific order to make the stator rotate clockwise or counterclockwise. By energizing the windings of the motor in a slightly different order the motor can be "half-stepped". Half-stepping decreases the torque produced by the motor but doubles the accuracy of the motor. The motors for this project were controlled by the computer in either full or half steps, depending on the user preference.

Solar cell

We wanted to measure the power of the solar cell as the platform scanned the sky. Attempting to track the cell's maximum power point is very difficult because both the current and the voltage are fluctuating. The short circuit current is proportional to the current produced on the order of millivolts, was amplified to several volts for the data acquisition card in the computer.

### Computer control

Before the computer started the scan, the program asked the user what angles was should the scan to take place, when the program should start and stop taking data, and how often the program should take data. The computer scanned the base and the arm of the platform through all angles of the sky. The short circuit current (sunlight intensity) and the angle were recorded.

## ANALYSIS

### Power vs Time Software

The analysis program, written in Turbo Pascal, asks for an array data file, a sky map data file, an output data file, and a modifier constant. The array data file contains data in one or both of the following formats:

```
array 180 90 4
arrayv 2.5 3.4 2.1 3
```

When the identifier "array" (not case sensitive) is used, the first two variables correspond to the angle and the third variable represents the solar cell area in $m^2$. When the identifier "arrayv" is used the first three variables are the x,y and z vector components of the array normal vector (the magnitude of the vector is not important). The last variable with the "arrayv" also represents area in $m^2$.

The sky map data file contains the data saved by the sampling program. The output data file contains the power vs time data. The modifier is an scale factor which converts the values from the DACA board to the power. The modifier is a variable because we wanted to be able to see the effect of using higher and lower efficiency solar cells.

## RESULTS

The graphs below are simulations of various array configurations on a fairly sunny day with some haze in the afternoon.

Figure 2 depicts the power available to side panels. The dip in the middle of the upper two curves is unexpected at first, but it has a simple explanation. When the sun is directly overhead, the side panels are not collecting any direct or reflected sunlight. In the morning and afternoon the side panels collect the sunlight directly in addition to the light reflecting off the pavement. The dip in power at about 11 is a cloud which briefly passed in front of the sun.

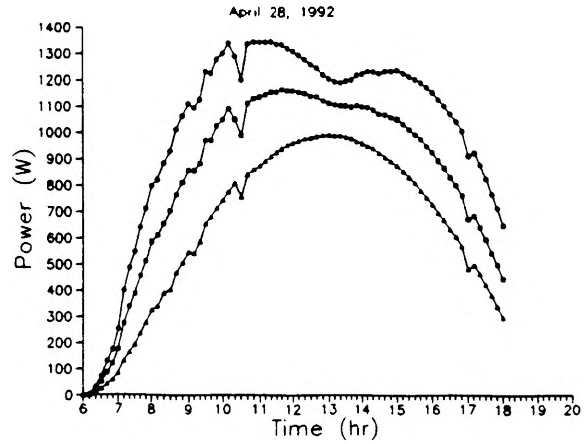


**Figure 2** Flat 8 m$^2$ with different side panels: top - 4 m$^2$; middle - 2 m$^2$; bottom - no side panels

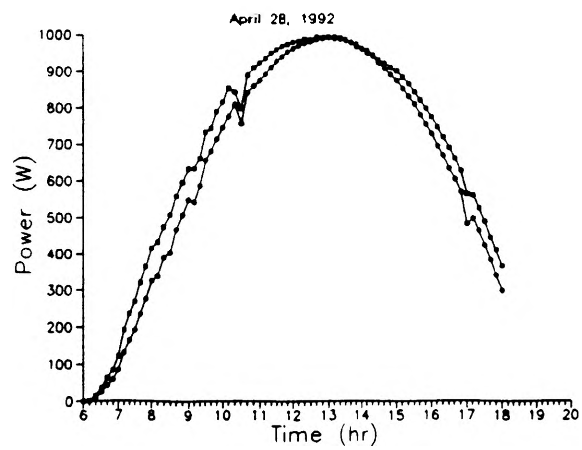


**Figure 3** Top curve represents a curved array while the bottom curve represents a flat array

Figure 3 shows a comparison of a flat and curved array (our design). Both arrays have essentially the same peak power but the curved array produces up to 100 more watts in the morning and afternoon.

Figure 4 shows two curved array configurations which were being tested. We had decided that we wanted a five faceted array and we knew the angles we wanted for the top and sides. The upper curve represents an array with smoothly twisting corners and the lower curve represents an array with triangular corners. The main advantage come simply from the fact that more solar cells would fit into the twisting array than the triangular corners array. From this information we decided to use the twisting array.

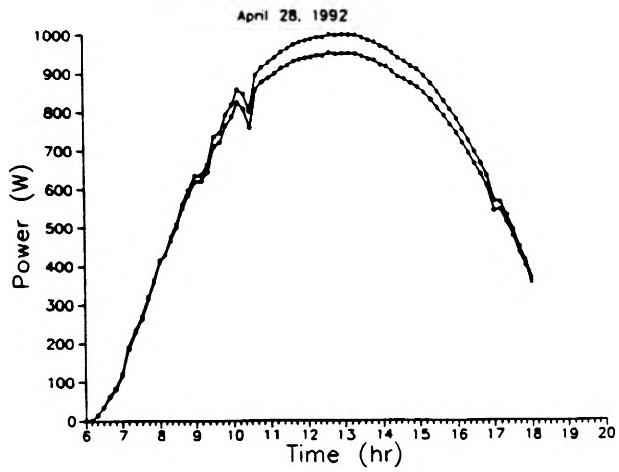


**Figure 4** Two five-faceted array options: top curve uses a twisting corner; bottom curve uses a triangular corner

## CONCLUSION

By accurately modelling the solar power production using the method described, the optimization between the array configuration and the aerodynamics shell can be taken from the level of "guess-timation" to true engineering. We are currently using this power simulation in the power management for the vehicle.


## ACKNOWLEDGEMENTS

The students role in the projects:

Jeff Shapiro - Set direction and goals for project
Rob Ziegler - Programmed most of the software used
Matt Spaethe - Built platform and programmed some of the code
Rick Jenkins - Built amplifier and stepper motor control circuits

We would like to thank Dr. Norman Cox and Dr. Don Sparlin for their advice.