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Solar car cruising strategy and its supporting system

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Abstract

Cruising strategy in a solar car race consists of the techniques used to generate as much power as possible under fluctuating weather conditions while cruising at the highest speed possible with minimal motor power consumption. This paper introduces the Cruising Strategy Supporting System used by the Honda Team for the third World Solar Challenge as a concrete example. This system consists of three base elements: Supervision Support, Cruising Simulation and Powder/Speed Optimizing Control.

1. Introduction

A solar car race is a competition among vehicles which have solar cells and secondary batteries, which must not exceed a specified capacity. Since almost all energy is generated from sunlight, the performances are affected by the weather to a much greater extent than ordinary automobile races. A solar car race is in effect a race to obtain energy by vehicles made as energy efficient as possible. The solar car developed by Honda for the 1993 solar car race is shown in Fig. 1 [1].

The foremost solar car race in the world is the World Solar Challenge which is held once every three years. This race starts at Darwin at the Nothern end of Australia, and goes all the way to Adelaide at the Southern end, a distance of approximately 3000 km. The car that maintains the fastest average speed wins the race.

The Honda Team has participated in the World Solar Challenge since the second one in 1990. At the third World Solar Challenge held in 1993, the Honda team won the title, and also won the 4th race in 1996. Each record broke the former record. Honda's Cruising Strategy Supporting System was one of the main reasons Honda won. This system was developed during the solar car development process in order to utilize the full potential of the car, in addition to boosting the efficiency of all individual components.

The Cruising Strategy Supporting System was developed to satisfy a number of objectives.

First, the team thought it was necessary to have the tools to clarify how the solar car should be run before the race, and that this system should be able to reflect the results of this process during the actual race.

It was decided that the following three elements were needed for the race:

1. The ability to transfer all information in the solar car in real time to the command vehicle, which runs behind the solar car.
2. Enable the command vehicle to perform analysis and projections for all data sent from the solar car, and use this information to determine the cruising strategy to enable high-efficiency, high-speed cruising of the vehicle.
3. The solar car to be provided with a system for running in precise accordance with the cruising strategy, without subjecting the driver to an undue work load.

The Cruising Strategy Supporting System design resulting from these precepts comprised three elements:

1. A "Supervision Support System" which includes all the hardware supporting cruising strategy.

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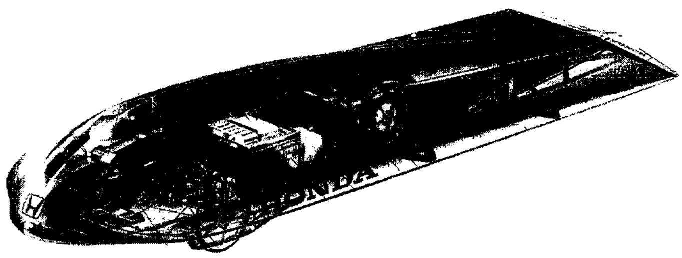

Total length	5.975m	Weight	189kg
Overall width	2m	Max. speed	140km/h
Overall height	1.02m	Body construction	Chassis + Body cowling
Wheel base	2.25m	Wheels	Two in front, one in rear
Tread	1.34m	Drive system	Direct motor drive to rear
Min. ground clearance	0.145m	Seating capacity	One

Fig. 1. Phantom view and major specifications of 1993 Honda dream.

2. A "Cruising Simulation Program," where the same power generation, power consumption and cruising result values as for actual cruising are obtained on a personal computer.
3. A "Power/Speed Optimizing Control Algorithm", incorporated in the ECU, which is on the solar car and automates control of speed and motor power in order to implement the cruising strategy.

These three system elements which were used in the third race are explained in this paper.

2. Supervision support system

2.1. Outline of supervision support system

This system provides the command vehicle with a variety of information on the solar car in real time while it is running, enabling the command vehicle to provide strategic support. The basic functions consist of real-time monitoring and data logging.

2.2. Configuration of supervision support system

The hardware configuration of the Supervision Support System installed in the solar car and command vehicle in shown in Fig. 2. The respective components in the system are explained in this section.

(1) Transmitter/receiver

The transmitter is installed in the solar car, and the receiver in the command vehicle. Data sent by the ECU via transmitter is unidirectional. A transceiver is used for instructions from the command vehicle to the solar car.

A compact, lightweight system (200 g or less) adopting the Frequency Shift Keying (FSK) method was used, with the capacity to set up to 16 frequency channels.

(2) Flat antenna

An S-shaped dipole antenna was installed on the upper portion of the canopy, shaped to minimize the resistance of the air and prevent any shadows from being cast on the solar cells. It was designed to be used jointly for the transceiver, incorporating a duplexer to reduce weight and enhance efficiency. The maximum transmission distance is 500m where the visibility is good.

(3) ECU

The ECU collects data on the respective components installed on the solar car by means of a monitor function and serial communication. All collected information is sent by the transmitter to the command vehicle. The ECU also provides this data to the driver by means of panel meters. Power/Speed Optimizing Control is performed by the ECU via a Power Drive Unit. The ECU also has the functions to enable the required calculations for remaining battery capacity and cruising distance during the race, storing these data. Data on approximately 300 items are collected.

(4) Panel meters

Information from the ECU is provided to the driver on the panel meters, which are also to set power and speed optimizing control functions.

(5) Receiver and monitor

(a) Since multiple receivers are used in the command vehicle, a divider is installed to divide the radio waves. A PC is used for monitoring, which is equipped with changeable five screens being provided for cruise management, remaining battery capacity and the other different functions.

(b) Measured data is stored on a 250MB hard disk, enabling it to be used as reproduction data on a monitor after completion of running, or details of cruising to be analyzed using MS EXCEL spread sheets.

(c) The monitor has a function to automatically issue a warning in the event it detects a breakdown in the on-board system. With this function, the judgement for important components is made by the ECU in the solar car, and a warning is issued to the driver and command vehicle. For items of relatively low importance, the judgement is made on the command vehicle monitor, with the only warning being issued to the command vehicle.

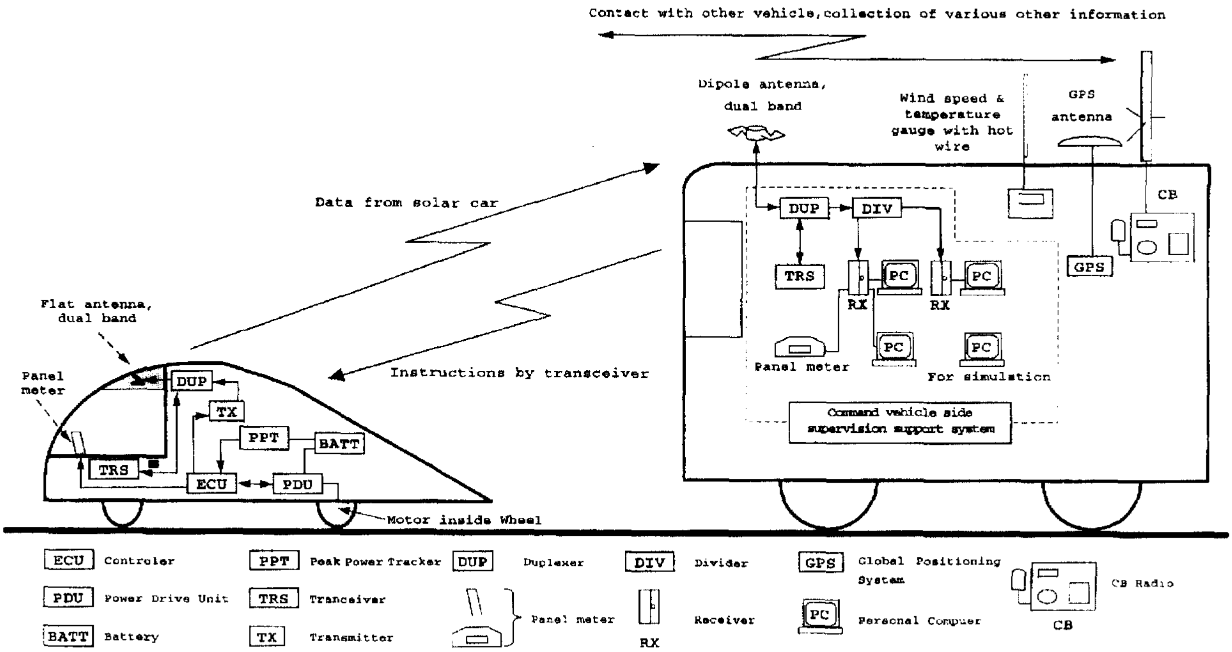

Fig. 2. Supervision support system hardware configuration.

3. Cruising simulation

3.1. Purpose of cruising simulation

A solar car race demands that energy be used as efficiently as possible to allow the vehicle to travel as quickly and far as possible. However, since environmental conditions continually change, it is very difficult to operate the solar car while satisfying these conditions. There are also many difficulties related to giving the driver instructions while crossing the Australian continent. Consequently, cruising simulation was used to satisfy the following three objectives:

(1) Establishment of power/speed optimizing control

In general, if a solar car is run on a flat road with no wind, the most efficient use of energy is obtained by operating at a constant speed. Naturally, these conditions do not exist during an actual race. If the car was run at a constant speed, the motor would reach its maximum load very quickly when going up a hill, substantially decreasing motor efficiency. And if the car was run at a constant power load, motor efficiency would again decrease when going up hills.

Next, giving precise instructions to the driver on the cruising pattern which should be used would unduly increase driver work load, and not achieve the precise cruising pattern we were aiming for.

In order to minimize the load on the driver and support team, and enable motor power to be controlled appropriately at all times in accordance with changes in the lay of the land and wind, it is necessary to create a Solar Car Power/Speed Optimizing Control System which effectively balances power consumption and speed.

(2) Establishment of place distribution

While the Power/Speed Optimizing Control described above is a type of micro control used from one moment to the next, pace control has a considerably longer span, and can be considered to be macro control. Even on days where the sun shines the entire day, the amount of power generated by the solar cells during the morning and just before dusk is dramatically less than the amount of power generated during the middle of the day. In addition, the car speed differs with the same motor power in areas where the wind is strong compared to areas where the wind is weak. In order to determine the best cruising policy under these varying conditions, it is necessary to gather a large amount of information and determine the optimum pace distribution to travel the fastest and furthest under a variety of weather conditions.

(3) Implementation of pace distribution during race

This consisted of determining speed and motor power through Power/Speed Optimizing Control and creating a projected schedule containing the remaining battery capacity, cruising distance and various other conditions.

3.2. Sample structure of cruising simulation

A general flow chart of the structure of cruising simulation is shown in Fig. 3. This flow chart illustrates the software used during the race for cruising simulation. The other types of simulation were performed to determine pace distribution and for application with

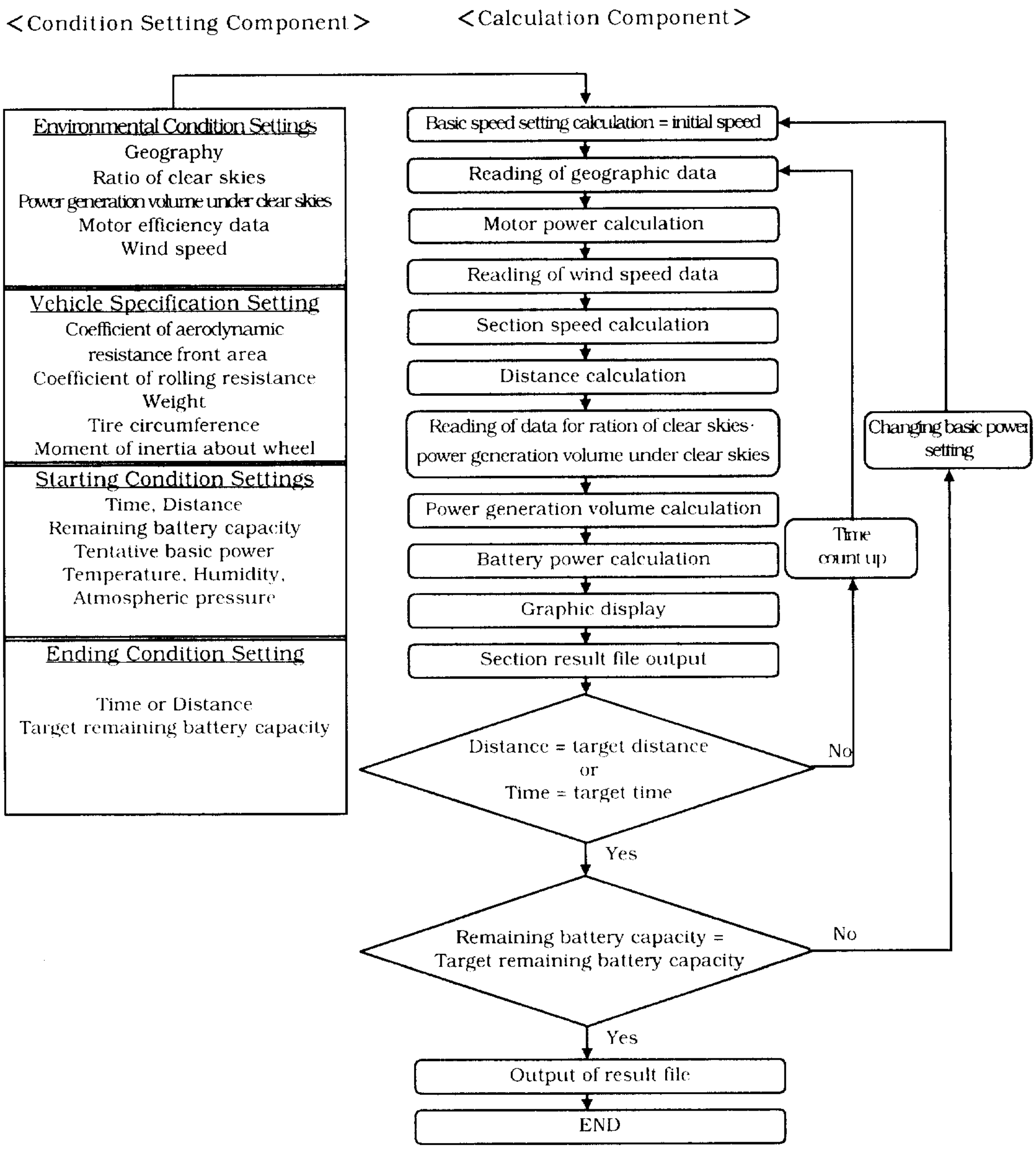

Fig. 3. General flow chart for cruising simulation.

Power/Speed Optimizing Control. Input data are the environmental conditions, vehicle specifications, status at the start of cruising and target value of remaining battery capacity at the end of cruising. Output data are Standard power setting and Standard vehicle speed setting to obtain Power/Speed Optimizing Control.

3.3. *Example of previous evaluation using cruising simulation*

This example consists of evaluation results to determine the most efficient and fast cruising strategy during alternating sunny and cloudy periods.

The conditions for simulation are as follows:

A cruising time of 8:00 am to 5:00 pm, as during the actual race. Power generation was set as 434 W at 8:00 am, with the volume gradually increasing to a maximum power generation value of 1529 W at 1:00 pm, decreasing from that time until a value of 566 W at 5:00 pm. Cloudy periods were included in the power generation pattern, with the amount of power generated amounting to 25% that generated during sunny periods.

Sunny and cloudy periods were set at alternating 20 km intervals. Simulation was performed for three cruising patterns; A–C with a constant battery consumption of 25Ah being used for all patterns.

(A) Cruising with a constant power of 315 W being supplied from the battery in addition to the amount of power generated. Specially, cruising where the speed is increased during sunny periods, with the speed being reduced during cloudy periods.

(B) Cruising at a constant speed from start to finish.

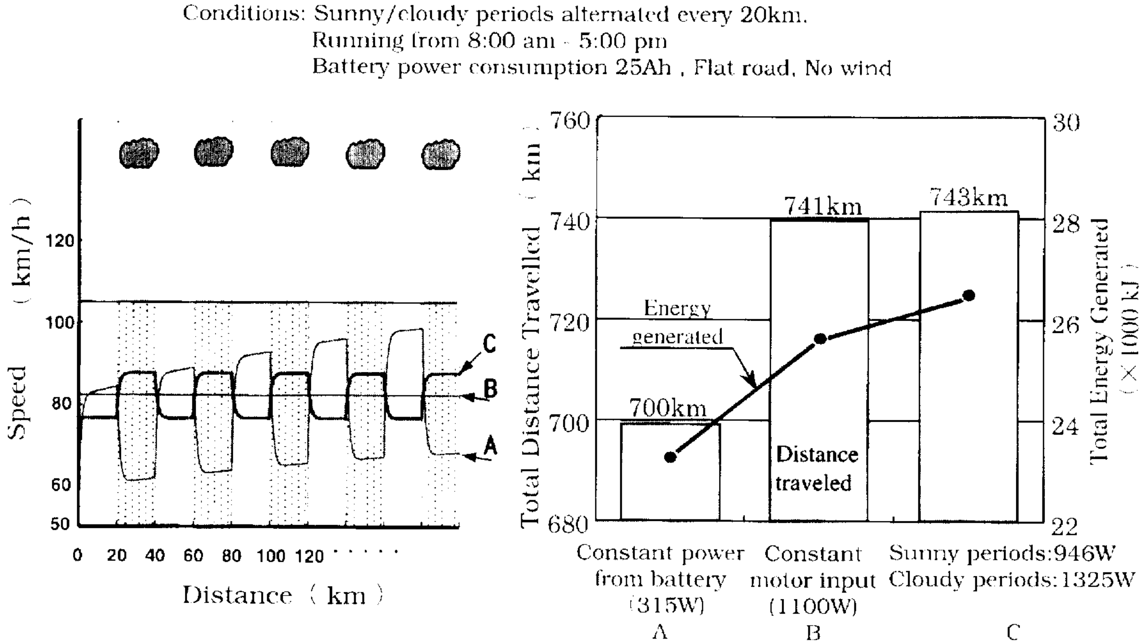

Fig. 4. Pace distribution for sunny cloudy periods.

(C) Cruising at a power of 945 W during sunny periods, with the power being increased to 1325 W during cloudy periods. Specifically, cruising at a higher speed during cloudy periods than sunny periods.

Most people would tend to think that since a solar car is propelled by energy generated from the sun, it is only natural that the car should be run slowly under clouds where the amount of energy generated decreases. but in fact, the most effective racing strategy is C, where cloudy areas are cruised through at high speed in the shortest amount of time possible, with the car cruising at low speed for an extended period through sunny areas in order to generate as much solar energy as possible. These results are shown in Fig. 4.

4. Power/speed optimizing control

4.1. Features & basic structure of power/speed optimizing control

An example of how power control was implemented based on power/speed optimizing control is shown in Fig. 5.

This example shows the motor power control lines for the vehicle speed which changes depending on road inclination and wind, where a standard vehicle speed of 84 km/h is obtained by the solar car on a flat road surface under no wind, with a standard motor input power of 1.2 kW.

When the vehicle speed increased beyond 95 km/h on a downhill slope, power to the motor was cut off to prevent an excessive increase in energy loss due to aerodynamic resistance, with the car cruising using its momentum.

By using the control line, if road inclination would change to +2%, speed would gradually slow down, therefore the control line would increase the motor power. In the end, the control line would converge into 72 km/h and 1.8 kW point.

This control strategy attempts to minimize changes in motor power and vehicle speed while allowing a certain amount of change. This enables the motor to be operated within a narrow rpm and power range, and in turn maximizes the motor performance.

This control strategy is the result of the evaluation of a number of different control lines through simulation.

The basic formula for the Power/Speed Optimizing Control calculations is shown below:

$$P = P_{set} \cdot (V_{set}/V)^3 \quad (1)$$

where

P = target motor power (W),
P_{set} = standard power setting (W),
V_{set} = standard vehicle speed setting (km/h),
V = vehicle speed (km/h).

4.2. Power/speed optimizing control processing in ECU

There are two motor control modes. The first is the manual mode, where the motor output torque is determined by the accelerator pedal position. The other is the power/speed optimizing control mode, where the settings are determined from Eq. (1).

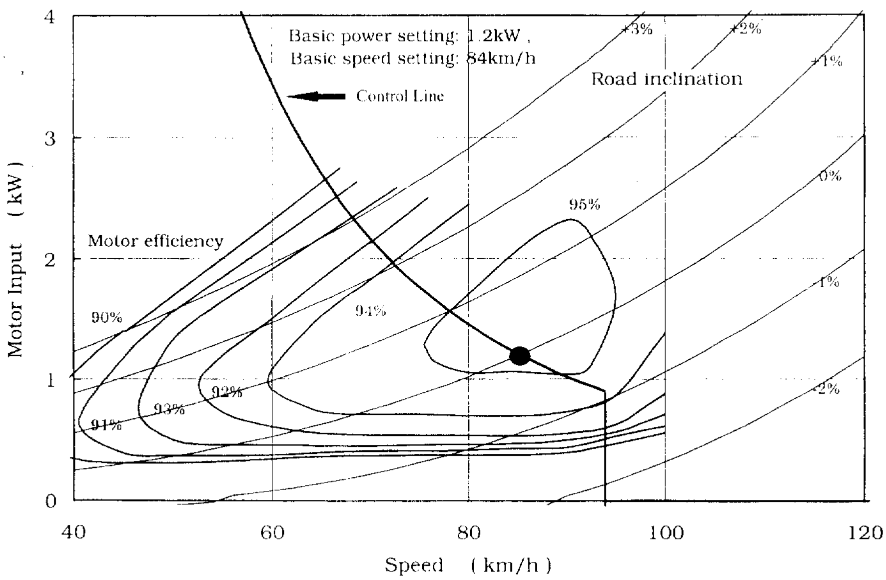

Fig. 5. Power-speed optimizing control lines.

(1) In the manual mode, the target motor torque is obtained from a map of the accelerator opening position and the vehicle speed.

(2) In the Power/Speed Optimizing Control mode, the motor power (P_{set}) and vehicle speed (V_{set}) when the cruise switch is turned on are used to calculate the target motor power value (P) once every second. The motor torque is controlled to obtain the target motor power (P) by means of PID control every 100 ms.

When the control mode is first activated, the upper limit vehicle speed and lower limit vehicle speed are obtained as limiter values for the Power/Speed Optimising Control mode. Optimum values for upper limit and lower limit vehicle speed are evaluated in advance through cruising simulation. The values used when control is started are determined from a basic speed setting table.

There are a number of other functions, such as a passing function to allow the vehicle to be accelerated to pass another vehicle by depressing the accelerator during the Power/Speed Optimizing Control mode without changing the basic setting for Power/Speed Optimizing Control. This mode can be cancelled by pressing the brake or pressing the cruise switch again, selecting the manual mode.

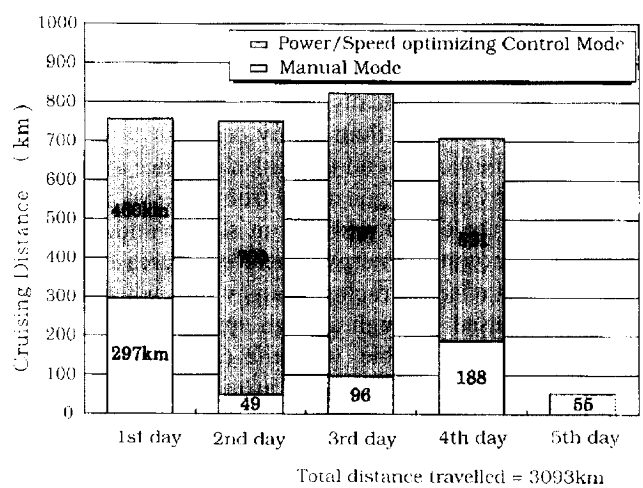

Fig. 6. Power/speed optimizing control usage frequency during race.

5. Conclusions

In the third World Solar Challenge, in addition to enabling trouble on the first day of the race to be quickly dealt with, the Supervision Support System was a highly effective tool during the race, being used for the measurement and analysis of all data.

Furthermore, as already stated, cruising simulation served as the brains for the formulation of cruising strategy.

As shown in Fig. 6, the car was run in the Power/Speed Optimizing Control mode most of the time.

As shown in Fig. 7, when the Power/Speed Optimizing Control mode was used during the race, the motor was maintained in the high efficiency zone.

Finally, it should be stated that unified management of this supervision support system, simulation technology and Power/Speed Optimizing Control enabled optimum cruising strategy support to be provided, achieving the described results. This would not have

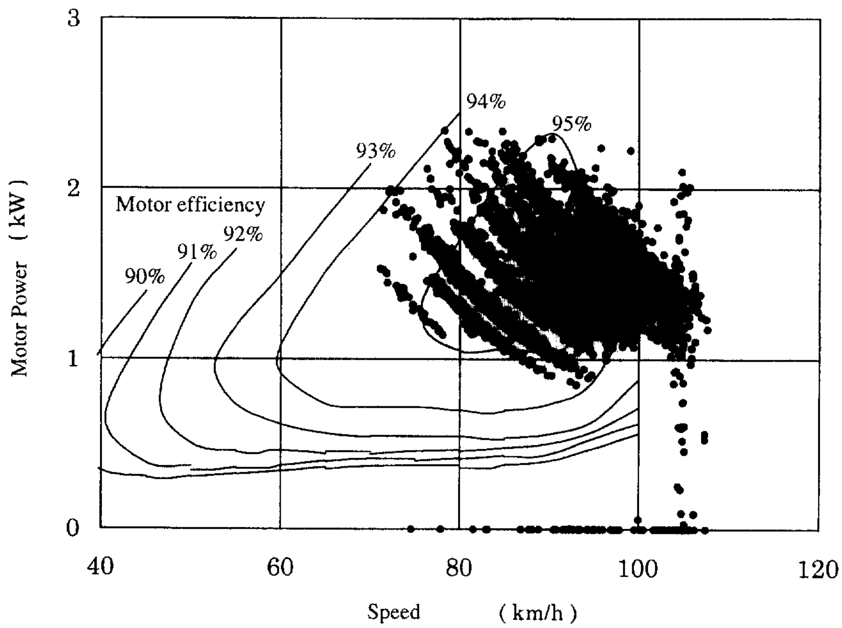

Fig. 7. Motor usage range during race while in power/speed optimizing control mode.

been possible if even one of these elements was missing.

In conclusion, we would like to state that we hope the information presented in this paper will be of use for improving the solar car race in the future.

References

[1] T. Iwata et al., Development of a solar Powered Vehicle in 1993 (In Japanese with English Summary), Honda R&D Technical Review, Vol.6, pp.1–16 (1994).