DESIGN & RACE COMPETITION OF A SOLAR POWERED VEHICLE

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ABSTRACT

This paper describes the performance of the USMA "Onondaga", a solar powered vehicle which completed the recent SUNRAYCE '95 event wherein 38 cars raced 1300 miles from Indianapolis, IN to Golden, CO. In particular, a rather simple and rugged solar array configuration, using only three diodes, was employed. Total cost of our vehicle was \$33,000, including spare parts. Furthermore the entire vehicle was constructed in-house, thereby qualifying us as the lowest cost entrant, designed, built and fielded by the smallest team! We also fielded the heaviest drivers. The authors goals were to qualify, to finish the race and to determine our vehicle capabilities, and in general to learn about solar powered vehicles. In all these, much to our gratification, we succeeded, finishing 26th overall in a field of 38, and on the last day of the race, finishing 5th! Our most satisfying event was day four, when the Onongada truly rode with the sun, covering 122.5 miles with minimal battery pack consumption. The project was initiated in August 1994, with the first semester devoted to design and the second to fabrication. During this project we had to conceive, design, procure, fabricate, test and evaluate and finally compete! Most competitors devoted two years to the project. The Onondaga was built from mid March to mid April, then subjected to 380 miles of road tests in the rolling hills of the Hudson Highlands. Road testing revealed numerous design flaws, several of which could not be corrected in time for competition. Therefore we procured the necessary spare parts and tools and adopted a generally conservative race strategy. The paper reviews the educational experience and reports on the performance of the Onondaga. We present: a brief description of the team and its operation and an assessment of the design process with recommendations for improvement. Also presented is a discussion of "scrutineering" (static and dynamic safety tests), discussion of the qualifying race as well as the full Sunrayce. Data presented includes vehicle amp-hour consumption, road elevation profiles, and typical solar insolation for the race. The paper concludes with recommendations for an improved Sunraycer.

INTRODUCTION

SUNRAYCE 95 was the third in a series of biennial intercollegiate competitions for solar powered cars, an educational event designed to challenge science, mathematics, engineering, business and other students throughout North America, and to foster scientific innovation and creativity. SUNRAYCE '95 took place from 20-29 June 1995, after the qualifying events during 14-18 June, in Indianapolis. Initially there were 65 registered teams. However less than 50 solar cars from throughout North

America, Puerto Rico and Mexico arrived in Indianapolis June 13 for a week of testing and qualifying to determine which teams made the final cut and competed in Sunrayce 95. Note that more than a dozen teams failed to meet milestones such as required technical reports, other documentation or did not complete their vehicles in time to compete. The remaining 45 cars went through a series of safety inspections and qualifying trials that narrowed the competition down to 38 solar cars. Before attempting to qualify, each car had to pass a rigorous inspection process called “scrutineering” to insure compliance with structural and safety requirements. Judges inspected each vehicle for drivability, turning, braking, electrical and mechanical soundness so-called “scrutineering” involved in-depth inspection and evaluation and breaking and slalom turning capability demonstrations. The qualifying event was a minimum fifty mile race. Of the 45 competitors to arrive at Indianapolis Raceway Park, 38 qualified. The United States Military (USMA) entry, number 27, the Onondaga, qualified in starting position 34 and performed exceptionally well in scrutineering and dynamic breaking on the raceway.

The SUNRAYCE series began in 1990. Based on their outstanding win in the first World Solar Challenge in 1987 in Australia, General Motors created GM SUNRAYCE USA for University students. In 1988, GM invited universities to submit proposals and thirty two teams were chosen for the inaugural event. The teams represented 19 states, Canada and Puerto Rico. The race began at EPCOT Center, Lake Buena Vista, Florida, on July 9, 1990. It covered more than 1,800 miles, traveling north through Florida, Alabama, Tennessee, Kentucky, Indiana, Ohio and Michigan. Eleven days later the race finished at the GM Tech Center in Warren, Michigan. University of Michigan placed first with an approximate overall average speed of 25 mph! Villanova, in 32 place, averaged slightly over 13 mph. SUNRAYCE 93 race started under cloudy skies in Arlington, Texas. Along the way, 64 kph (40 mph) winds, torrential rains, lightning storms, and hills too steep for worn down batteries to climb, challenged the teams. The weather served to divide the field, and the only solar car to make it to the finish line every day, under its own power was the University of Michigan entry, “Maize & Blue”, which won the race by 90 minutes, averaging 27.3 mph as they raced from Texas to Des Moines. According to race officials, major factors that seemed to influence placing were reliability and practice time. The top ten cars averaged 800 miles of practice before the race, while those in the last ten positions averaged only 160 miles! Getting enough practice, learning to solve problems, good planning, organization and teamwork all increased chances of finishing at the top. At the USMA, our team completed the Onondaga in early April and completed approximately 300 miles of road tests, sufficient to pinpoint vehicle defects, but not early enough to make any major modifications. Massachusetts Institute of Technology was the winner of SUNRAYCE '95 averaging 37.23 mph, and finishing just 18 minutes, 49 seconds ahead of second place University of Minnesota. USMA finished 26th at 13.80 mph. Eleven vehicles did not finish the last day and meanwhile the University of Quebec and two time SUNRAYCE winner, University of Michigan, had dropped out of the race! Figure 1 is a schematic of our Sunraycer and its finite element model. Table 1 summarizes the fleet performance, day-by-day, in terms of the average speed achieved that day. Again, note USMA position via italicized numerals. Also indicated by underlining, is the range of 15-18 mph. This is the speed range which an experienced senior engineer from Solectria Corporation estimated that the Onondaga could be expected to achieve over the race route! In the following paragraphs the evolution of the USMA team, the conduct of the project and final vehicle performance is discussed. Data review herein suggests that, except for the unfortunate second day strategy, the Onondaga was capable of finishing in the top fifteen competitors. But let us begin at the beginning.

TABLE 1

SUNRAYCE FLEET: 'DAILY PERFORMANCE

Day 1	2	3	4	5	6	7	8	9
36.13	38.46	43.7	47.73	36.16	36.91	50.42	42.58	20.17
36.1	37.89	42.83	46.96	30.5	34.89	49.36	41.15	<u>19.39</u>
35.16	36.44	42.74	46.59	29.43	33.7	43.04	40.82	16.53
34.97	36.04	40.79	43.25	27.91	29.54	42.52	39.09	<u>15.89</u>
33.74	35.77	39.63	42.42	26.85	29.5	41.04	34.27	13.3
33.52	34.59	37.59	38.72	24.44	28.3	39.41	34.06	11.19
33.15	30.9	34.52	36.27	23.41	26.28	37.73	32.36	10.41
32.78	30.37	33.92	35.82	21.61	24.72	34.17	31.53	8.97
32.25	29.84	30.95	34.84	<u>21.6</u>	23.6	33.38	28.53	8.7
31.41	29.4	29.81	34.71	17.83	22.93	31.92	<u>20.65</u>	8.55
31.02	29.15	28.17	34.5	16.3	21.04	30.79	17.76	8.49
29.53	28.95	27.24	33.97	16.21	20.46	30.7	17.76	8.35
29.49	28.02	27.12	28.12	<u>15.17</u>	18.68	26.99	17.67	8.35
28.37	27.99	26.84	27.57	<u>14.94</u>	<u>18.68</u>	25.23	16.93	7.85
28.23	27.81	26.25	25.92	14.87	<u>17.51</u>	24.05	16.48	7.85
27.54	27.53	25.6	24.28	14.59	17.42	24	16.24	7.79
27.03	27.33	25.28	23.37	14.52	17.1	23.55	15.87	7.36
25.83	27.02	24.81	<u>20.09</u>	14.05	16.92	23.51	15.1	7.21
24.48	27.01	23.35	17.8	13.61	16.86	21.74	<u>14.9</u>	7.16
24.32	25.81	23.24	17.41	13.25	16.02	21.3	14.77	7.02
23.89	25.59	22.66	16.94	12.97	<u>14.37</u>	20.99	<u>14.71</u>	7.02
23.07	24	22.12	16.35	12.54	14.24	19.74	14.58	6.98
22.83	23.39	21.22	15.98	11.82	14.03	19.1	14.4	6.93
22.74	23.19	<u>20.33</u>	15.98	11.59	14.03	<u>19.09</u>	14.28	6.83
22.29	21.55	<u>17.23</u>	<u>15.74</u>	<u>11.25</u>	13.46	<u>16.74</u>	13.71	6.79
21.3	<u>20.63</u>	14.08	<u>15.28</u>	10.89	12.53	15.71	13.71	6.76
21.02	20.3	13.9	<u>13.86</u>	10.73	<u>12.39</u>	15.71	13.6	6.74
<u>19.65</u>	20.22	13.34	13.8	10.66	11.54	15.14	13.49	6.66
<u>17.45</u>	<u>19.87</u>	13.34	13.8	10.51	11.43	<u>15.01</u>	13.34	6.46
<u>16.13</u>	16.68	13.34	13.3	10.33	11.4	14	13.03	6.34
<u>14.4</u>	15.41	12.77	13.28	9.94	11.28	13.88	12.46	6.26
13.4	<u>15.25</u>	12.77	12.79	9.8	11.01	13.67	11.2	6.1
12.94	<u>14.57</u>	11.14	11.87	9.47	9.75	13.08	10.95	5.91
9.5	14.37	10.7	11.43	9.47	9.57	12.91	10.85	5.63
6.78	11.57	10.02	11.27	9.47	9.41	12.67	10.74	4.74
6.67	11.27	9.87	11.19	9.47	9.41	12.57	10.05	3.99
6.34	10	9.87	10.88	6.32				
5.96	7.85	9.87	10.58					

Quebec
Michigan
Quit

Figure 1. United States Military Academy Sunraycer 1995, Schematic & Finite Element Model.

USMA TEAM ORGANIZATION

Prior to the SUNRAYCER PROJECT, the designated Project Director, with the support of the Civil-and Mechanical Engineering Department Head and Academy Dean, offered a week-long design workshop for all faculty members. This workshop dealt with generalities, including: comparison and contrast of traditional versus the holistic paradigm of engineering education. The following topics were treated.

- . Various approaches to nurturing creativity and developing creative thinking skills.
 - . Comparison and contrast of traditional versus holistic approaches,
 - . Discussion of various educational theories,
 - . Brief introduction to the SUNRAYCE'95 competition.
 - . Discussion of various design methodologies and teaching strategies for developing both critical and creative thinking skills.
 - . Actual design experience.
 - . Attempting to develop a stronger sense of community among the participants.
- Meanwhile the program director independently prepared and submitted his proposal and committed USMA for the competition. SUNRAYCE '95 was offered to the cadets as a two semester "capstone" design.

Initially thirty five cadets expressed interest in the project, then twenty eight cadets enrolled and were assigned to 7 teams of up to 6 cadets. The project director was joined by seven faculty members, most from the Civil and Mechanical Engineering Department, and one from Electrical Engineering(the senior author, then a visiting professor at USMA), and one professor from Behavioral Science. These faculty led the volunteer teams, consisting of:

- . Aerodynamics of the Body
- . Race Strategy
- . Vehicle Chassis
- . Vehicle Suspension & Road Handling
- . Electrical Propulsion
- . Cockpit Ergonomics
- . Solar Cells

In the first two weeks of the fall semester, nine lecture hours were presented covering these topics:

- . Design as problem solving
- . Creative and critical thinking skills
- . Communication skills and group dynamics
- . Professional and environmental ethics
- . Introduction to the SUNRAYCE '95

The project was then turned over to the seven teams, whose objective was to complete an integrated design by semester's end. To assist communication and integration, periodic Saturday classes were scheduled. SUNRAYCE was a demanding project, far more intensive than typical design courses. During intercession, the designs were thoroughly reviewed by the faculty and various deficiencies were identified. Incompatible subassemblies, total lack of adequate engineering drawings, and gross inadequacies were noted and reported back in the second semester. The fall semester had been far more time consuming than many students anticipated. Eight cadets and two faculty chose not to continue. The spring semester required completion of an adequate design, since at this stage there were major incompatibilities (ex uncertain rear wheel axle and motor and gear mounts, etc.) and several

unidentified and inadequate components. As the faculty addressed design details, the twenty remaining cadets-were assigned to groups as follows:

- . Metalworking
- . Composites
- . Electrical Propulsion System
- . Race Strategy & Logistics

Cadets were asked to select team leaders and overall cadet project leader. The first assignment was to set program milestones, which are shown in Table 2. Considering these milestones, the number of cadets and their available time, early in the semester it was apparent that the vehicle could not be successfully completed in time. Accordingly the authors devoted full time and every spare moment to the solar vehicle fabrication and subsequent road tests. By spring break the situation was clear. Without accelerated effort, the ONONDAGA could not be completed by semesters end. Therefore after the spring break three civilian faculty members increased their efforts along with three technicians and machinists. The returning cadets were tasked in their final phase to complete formal documentation including assembly drawings, part specifications, circuit diagrams. Besides the documentation effort, cadets were assigned to road testing, and race preparation, logistics and strategy. Meanwhile interaction with manufacturers and component suppliers had deteriorated and critical delays had to be remedied by constant harassment of the suppliers. Nonetheless the vehicle was completed and rolled out on 15 April for test and evaluation. Before discussing the road test phase, let us describe the solar array and electric propulsion system.

SOLAR ARRAY

The solar array measured 2 by 4 meters and consisted of three types of arrays of laminated polycrystalline silicon cells, purchased from Solarex at a cost of \$7,850. The ultralight laminates encapsulate the silicon cells between layers of clear Tedlar, clear EVA and opaque Tedlar backface. One type module consisted of a 4 X 10 matrix of individual 9.5 X 11.4 cm cells (14 of these at 99.76 X 41.98 cm) The other modules consisted of 26 and 33 cells respectively. The eighteen large laminated solar arrays were connected in three circuits, each having six laminated panels and a separate diode. The entire array was wired to a battery pack of seven Delco heavy duty deep charge batteries, contained in a fan-ventilated composite box.

PROPULSION

We chose a Solectria motor, 120 volts, rated 5 hp (8 kw) continuous and 15 hp peak power(\$2450) with a controller costing (\$2950). From the same company we purchased an amp/hour meter(\$450.) Solectria's brushless motor featured rare earth (Neodymium-iron-boron) magnets. It also had a two position switch to double torque, and the controller provided current controlled stepless regenerative braking. The motor (operating at 6000 rpm) was connected via a transmission with an approximate six-to-one gear ratio. The battery pack was accessible by removing a bolted-on cover. Furthermore all fuses and switches were placed on the exterior of the battery pack. Fuses and the majority of connections were visible through the transparent polycarbonate plastic cover. The driver control panel had a multi-position switch which allowed measurement of individual battery voltage and current, as well as overall battery pack performance. We did not install a speedometer. Instead there was an amp-hour meter which permitted observation of power consumption and remaining battery pack power. The amp-hour meter had a red and green light indicator, with green meaning no battery power consumption. The objective was to drive in the "green" as much as possible

TABLE 2

"USMA 'SUNRAYCE '95" MILESTONES

Team	Jan	Feb	Mar	April
METAL WORKING				
Seven cadets	<i>Layout & construct Chasis</i>	<i>Layout & Construct Front Suspension Rear Suspension</i>	<i>Instill Steering Install rear brakes Install front brakes</i>	<i>Install Cockpit</i>
COMPOSITE WORKERS				
Six Cadets	<i>Dimension Battery Box Tutorial and practice composite fabrication</i>	<i>Construct Kevlar Epoxy Box with Fan Construct G/ass/Epoxy Box Design Solar Array Panel</i>	<i>Fabricate Solar Panel Design & Fab Chassis Attachments</i>	<i>Construct Chassis body Paint, Wax, Decorate Onondaga</i>
PROPULSION TEAM				
Four Cadets	<i>Dynamometer tests</i>	<i>Battery Tests Wire battery Box</i>	<i>Wire Solar Array Install Motor/.Controller</i>	<i>Wire Cockpit, Gages, Fuses</i>
STRATEGY & LOGISTICS				
Three Cadets		<i>Develop Race Strategy & Logistics Plan</i>		

ACTUAL ONONDAGA ROLL OUT DATE :15 APRIL

STRUCTURAL-INTEGRITY

A number of three and four wheel chassis, body and solar array configurations were treated. [1 - 5] The ALGOR finite element analysis(FEA) code was used to calculate stress distribution for a number of preliminary structural designs and the selected design was analyzed in depth. The FEA model is shown in Figure 1, there were 57 beam elements used in the calculations and ten separate loading condition, as required by Sunrayce regulations were completed. In addition critical structures tests were conducted on representative, welded joint sections and on the solar panel attachment concepts and the solar panel sandwich panel. Chassis materials considered include aluminum, steel, and glass, graphite and Kevlar epoxy composite tubes. Five different combinations of chassis tubing were analyzed: all steel with different size tubes, all aluminum, hybrid of aluminum and steel tubes and several types of reinforced plastic tubes. Four load cases were used in the preliminary design stage, namely: 4 G bump, 1 G turn, 1 G braking, and all three loads superimposed. Estimated gross vehicle weight was 850 pounds. All stresses were considerably less than material strengths and yield stresses. The lightest weight chassis design was a graphite/glass/epoxy composite at 27 lbs, next a hybrid aluminum/steel chassis at 30 lbs and a steel chassis with a heavy roll bar, at 68 lbs. Our cadet team was familiar with bending and welding steel, but had no experience with aluminum or composites, therefore the all steel design was chosen. This utilized chrome/moly steel which was available in standard 24 foot lengths. The chassis was laid out to place weld joints at lowest stressed regions. This resulted in 27 welds, and accordingly tests were conducted on representative weld joints. Tension tests were completed on straight tubular sections which had their ends crushed to fit in the wedge-acting grips of our MTS universal testing machine. These tests gave lower bound strength results averaging over 120 ksi. Tests on oxyacetylene welds with straight and "T" specimens failed at values ranging from 14 to 36 ksi for straight and 6 to 15 ksi for "T" welds. Electric-arc resistance welds produced substantially higher strengths, and the arc welding method was used for the steel chassis. For structural integrity assessment, crash analyses were completed for 5 G rear, front and side impacts, for top and side impacts at 1 G, and for 3 G sideways and frontal roll-over at 0, 30 and 60 degrees. Maximum calculated stresses in the various chassis elements for the different load cases are summarized in Table 3, and a schematic of the vehicle and tabulated weight distribution is in Figure 2.

SOLAR ARRAY STRUCTURE

The laminated photovoltaic cells were supported by a sandwich panel with face sheets of a single layer of 15.5 oz. sq.yd. Kevlar/epoxy with several different core materials(high temperature foam, and 1/8th and 3/8th inch Nomex honeycomb cells), framed with spruce and with four mahogany inserts(one inch thick, and 6 X 6 inches) for attachment fixtures. The laminated modules were attached using an edge frame of high temperature double sided polyurethane adhesive tape, 0.75 inches wide and capable of sustaining tensile loads of 38 lbs per inch of tape. The panel and cells weighed approximately 120 pounds and was clamped via four steel "U" brackets to the chrome/moly steel tubes of the chassis. Note that by unbolting two of the panel attachments, the array could be pivoted about one side of the chassis to optimize charging position. Load versus deflection, and creep tests conducted on solar panel sections confirmed structural adequacy.

TABLE 3. MAXIMUM STRESSES; USMA SUNRAYCER

LOAD	TENSILE STRESSES, psi		COMPRESSIVE STRESSES psi	
	Chassis Element	Stress	Chassis Element	Stress
Rear Impact, 5 G	E 23,24	2870	E 18,19	8076
Front Impact, 5 G	E 25	2532	E26,27,38,39	5973
Side Impact, 5 G	E 39	28137	E 26,27	28305
Top Impact, 3 G	E 1	5697	E 29,36	5792
Frontal rollover, 60D	E 23,24	7392	E 43,45	17569
Frontal rollover, 30	E 23,24	5668	E 43,45	13647
Sideway rollover, 60	E24	8531	E45	23752
Sideway rollover, 30	E 39	16560	E 45	19728
Front Bumper, 5 G	E 25	3267	E 17,20	9383

Component Weight and Coordinate Data

Number	Type of Component	W (lbs)	X (in)	WX	Z (in)	WZ
1	Chassis	64	82.0481	5251.078	52.3571	3350.854
2	Solar Panel	140	152.7781	21388.93	66.8409	9357.726
3	Battery Box	330	88.0381	29052.57	44.9071	14819.34
4	Driver	180	57.3192	10317.46	52.018	9363.24
5	Motor	30	150.497	4514.91	41.2039	1236.117
6	Front Suspension	5	30.3629	151.8145	37.0622	185.311
7	Rear Suspension	30	161.414	4842.42	40.7336	1222.008
8	Front Wheels	3	30.3629	91.0887	30.555	91.665
9	Rear Wheels	5	171.4184	857.092	36.9151	184.5755
10	Controller	25	139.551	3488.775	41.8978	1047.445
11	Misc.	38	98.5	3743	50	1900
TOTALS & CG		850	98.47	83699	50.30	42758

Figure 2. Preliminary Design Vehicle Weight Distribution and Center of Gravity.

SCRUTINEERING

Challenger “Scrutineering” occurred 15 June Thursday, at Indianapolis Raceway Park. This involved passing six test stations manned by Sunraycer marshals as well as weighing the vehicle in ready-to-operate configuration, including driver. (We weighed in at 1150 pounds). Of concern were: *sizing, turning radius, body, electrical and mechanical* constraints as prescribed in the SUNRAYCE regulations. As for electrical, the simplicity and unconventional approach(no power trackers) led to some discussion with the race officials. We had to provide a several additional safety signs and were delayed by our “mystery fan“, which continued to run with the battery box in off position. This was shown to be due to incident indoor light on the solar array! Zero leakage was observed on all contacts, and uniform torquing of battery posts was demonstrated. Regarding mechanical considerations, some questions asked were: What torque was used on the on the grade 5 bolts. What kind of steel? Did you preheat welds? Air cooled afterwards? At first it was felt that there was too much rack on rack and pinion, but after a few test on steering, we got the green go-ahead. Additional questions were: Solar panel attachment design and verification. (Our tests showed that the solar panel attachments were capable of at least 450 lbs in direct tension). What kind of axle(rear)? (axle from an all-terrain vehicle.) Body material? Battery box material. (Kevlar/epoxy with balsa wood and/or 4 pcf polyurethane foam) Safety cable on rear end? Two Nylocks were missing from brake pedal, and we needed cable stops on front brakes, locktite on motor mount nuts. Subsequently our vehicle successfully completed the dynamic braking test at 30 mph.

SUNRAYCE QUALIFIER

On Saturday 17 June, we qualified by averaging 27.89 mph over 27 laps at the Indianapolis Raceway. During the qualification race there numerous problems with a pit stop in the 4th lap, in the 11th lap David Cook our driver detected sounds of bearing failure so that in the 15th lap the right front wheel bearings were replaced. In the 24th lap the amp-hour meter battery was replaced and at the end of the 27th lap it was discovered that the motor controller bracket mount bolts were loose. Total running time was one hour forty eight minutes and twenty eight seconds, during a warm sunny day. Following the qualification race, Sunday was spent charging the battery pack, replacing the amp-hour meter and overall inspection and maintenance of the Onondaga.

THE USMA SUNRAYCE

DAY 1: INDIANAPOLIS TO TERRE HAUTE, IN- 65 miles, 20 June 1965. Total race time 3 hours 51 minutes, start time approximately 10:27 am. The race caravan proceeded through city streets coping with traffic, man holes, railroad crossing, many bumps ,road construction, etc. The day was bright and clear, except for a slight and temporary haze, which slowed Columbus State to a crawl on one of the steeper slopes. We encountered several hills, including one long and one short and steep(10 degrees?), and our motor controller did not overheat! We arrived at Rose-Hulman Institute with 13.5 amp hours of power remaining and proceeded to charge from 1430 to 1730 so that we had a fully charged battery pack by dusk. Charging activities were interrupted by a thunderstorm, accompanied by pea-sized hailstones. We had about a half hour warning and put the vehicle under cover for the storm duration.

DAY 2:- TERRE HAUTE, IN to ALTON, IL 169 miles. This day the faculty advisor of the race strategy team took charge. All three drivers were used, and what might be termed a “Custer” strategy

was adopted. Throughout the day, vehicle speed was increased. Admonishments by other faculty members not to use more than 40 amp-hours of power were ignored, along with our suggestions to reduce speed to conserve energy and for safety considerations. During the day due to bad wheel wobble, we stopped on several occasions to tighten wheel spokes, to replace a blown tire, and change the front wheel bearings. There was no shoulder and "S" curves predominated with high embankment along many stretches of the road. Fortunately we arrived intact, but coasted in with absolutely no power remaining and no time for charging that evening. According to our amp-hour meter, 64 amp. hours had been consumed.

DAY 3- ALTON. IL to FULTON, MO -165 miles. The task before us was to recover and recharge as soon as possible (we elected not to replace the battery pack due to penalties). According to Delco's expert Dan Praeder, we needed to charge 10% more than the amount discharged. This morning, starting at 0600, the Onondaga achieved 16.5 amp hours recharging. Since our goal was to recharge, we set a leisurely pace, allowing numerous competitors to pass, and attempting to use our regenerative braking wherever possible. After driving 25.8 miles we stopped and charged at Pierre Marquette Park, and did wheel and bearing changes, tuned brakes, etc. We loaded the racer at 16:17 and trailed to the next stop, still with an under charged battery pack.

DAY 4- FULTON, MO - LEE'S SUMMIT, MO- 156 miles The morning's race observer paid strict attention to backup traffic insisting that no more than a half dozen cars be allowed to form behind us and we had to pull over 15 times during the day, onto gravel shoulders. Each stop caused unnecessary damage, and each stop and start consumed about 0.5 ah, depending on slope and driver. and so we lost about 7 amp hours! Our team members were irate since many of our competitors ignored the traffic and had dozens of vehicles trailing behind. Nonetheless our goals for the day were to "ride-with-the-sun", that is to minimize energy consumption and with the aid of the green charging light indicator of the amp-hour meter, determine speeds for minimum energy consumption. With the exception of one short rain storm, it was a bright, reasonably sunny day. We arrived after dark after completing 122.5 miles with an estimated 33.34 amp-hours remaining!

REST & CHARGING DAY AT LEE'S SUMMIT. MO

The day of charging started at 06:00, there were intermittent thundershowers starting noon, and it was a hazy day otherwise. About 13:00, just after first rain squall, we covered the racer with foam and bubble-plastic to protect against hail. there were continuing squalls, and we stopped charging at 17:03 as ONONDAGA rolled into sheltering tent. during the afternoon there were three thunderstorms: from southwest, northwest, southeast. During the day, four front bearings were replaced. Note these were expensive SKF bearings, and there were varying degrees of damage. We replaced the left front wheel, giving us two new front tires. The "old" rear tires were deemed adequate.

DAY 5 of race - LEE'S SUMMIT.MO-MANHATTAN. KS 152 miles

The day began with raining, haze and cloud cover. We changed front tire pressures to 65 vs 68 this day. After about 10 miles of travel the front wheel developed loose spokes after hitting several pot holes. We replaced the front wheel. This day we raced about 51 miles.

DAY 6 MANHATTAN, KS to SMITH CENTER. KS 150 miles

This was another hazy day, with drifting clouds. About noon, Onondaga was traveling so slowly that eighteen cows ambled toward us and followed for awhile! In the next half hour this happened three more times, the last time a jealous bull herded the cows away! By one o'clock the sun shone brightly

and the Onondaga cast a shadow! During this day both drivers dozed momentarily and wandered across the lane! At 15:30;more sunlight and bunches of small blue butterflies hover over the blue solar array. Later in the evening we found the retaining split snap ring had slipped out of the rear axle groove. This could have occurred due to the rough, pot-holed road, the shoulder rumble strips, it could have been exaggerated by regenerative breaking or it might have occurred when the Onondaga was being unloaded and the loading ramp was kicked sideways. In any case the motor mount and brake, as well as the snap ring were repaired and wheel bearings and spokes repaired & maintained as well. After running for 76 miles we stopped and charged for the next day. We towed Onondaga, leaving about 6 pm and arriving at Smith Center around 19:45 pm. This turned out to be a good decision, since shortly after we loaded up and started trailering in a heavy thunderstorm deluged us. We passed three SUNRAYCERS stranded in the in the heavy downpour!

RACE DAY 7: SMITH CENTER TO ST. FRANCIS 166 miles

A rough start consumed 1.35 amp hours and within a half hour the left front wheel was observably wobbling. Shortly thereafter the wheel was flat and had to be replaced. The flat tire had a split seam, with the tube having about an inch long tear. This left us with no spare so Cadet Purdom set to repairing our other wheel, completing that task within 90 minutes. We pulled over for traffic six times and had two pit stops for drivers. About 16:00, the driver of the chase van dozed off, running onto the shoulder. The occupants shouted him awake in time to avoid an accident ! Onondaga packed in at 17:40 having completed 97.5 miles for the day.

DAY 8: ST. FRANCIS, KS to AURORA. CO 171 miles.

Once again the left front wheel had a bad wobble from the start, (rough handling to start line and over gutter?) After an hour we changed the wheel, which had 4 loose spokes. This took about 13 minutes. The lunch stop took 18 minutes. and shortly after starting a storm front moved in. In addition the road was rough so the driver rode the shoulder, which was less rough. About 13:16 a local crop duster plane tipped wings and buzzed the Onondaga. Shortly afterward a boy on a bike raced us at 23 mph for about 8 seconds. At 14:42 we stopped to assist the scout vehicle, whose door flew open and would not shut properly. At mid-day changed drivers and raced until 15:52, having covered 103.2 miles. We trailored in at 16:23 and shortly thereafter a heavy thunderstorm hit us. We rode past two herds of buffalo(78 and 63 buffaloes respectively, no old bulls). Arriving in Aurora we parked under the high school stadium, during a cold heavy down pour with Onondaga showing 32.6 amp-hours.

DAY 9: AURORA TO GOLDEN, CO 52 MILES.

The day was cloudy and raining. After another rough start at 11:17 our left from tire was going flat, as we stopped the tire blew out. About 17 minutes to change to new wheel, and we raced again. Cadet Dave Cook at the wheel. At 11:51 the Iowa State Sunraycer spun out, with the driver suffering a broken leg. Meanwhile our left wheel again had a bad wobble! Lack of sun meant all vehicles were running off battery power. On the steep grades we slowed to about 14 mph, creeping along to save energy. Meanwhile we were passing numerous competitors. At 1310. a [pit stop for the driver. On the road again, after a severe bump, the left wheel wobble had disappeared! By 14:00 we were out of power a few hundred meters from the crest of the last long hill into Golden, CO. At the crown of the hill, Onondaga had consumed 57.62 amp hours. Discussion with the Sunrayce observer insured us that if we pushed the vehicle in one continuous 15 second push, there was only a half hour penalty. So two drivers and one faculty team member started the uphill push, then the chase vehicle driver switched with the Onondaga driver and we topped the last rise. Riding down the long incline, our driver used regenerative breaking and crossed the finish line in 5th position for the day! USMA finished 1hr:04

Trip Profile

Figure 3. Race Road Profile.

Figure 4. Solar Insolation for Seven Days. ”

TABLE 4 SUNRAYCE '95: USMA SUMMARY

Date	Event	Miles	Actual Miles	Amp-Hours(AH) Consumed	Ave. AI+/Mile	Official Speed
Jun 17	QUALIFIER	50	51			27.7
Jun 20	1	65	75.8	13.5	0.178	16.13
Jun 21	2	169	157.2	62.4 <i>See note*</i>	0.397	20.63
Jun 22	3	165	25.8	2.92	0.113	10.7
Jun 23	4	156	122.5	6.66	0.0544	15.74
Jun 24	Rest Day					
Jun 25	5	152	50.8	26.29	0.517	11.25
Jun 26	6	150	76.05	14.03	0.184	12.39
Jun 27	7	166	97.45	4	0.041	14
Jun 28	8	171	103.2	32.02	0.31	14.71
Jun 29	9	52	52.1	25.41	0.488	13.3
	Totals	1296	811.9			
	Completion %		62.6			
	Road Test Miles		380			

SOLAR PANEL & Event Charging			BATTERY PACK STATUS	
Qualifier	Race Day	am pm	Start	Finish
	1		62.4	62.4
	2	0 0	62.4	0
	3	16.5 24.77	16.5	38.35
	4	13.79		33.44
Rest	For day: 25ah			
	5		62.4	35.11
	6	10.66 8	45.11	31.74
	7	16.37	48.17	44.17
	8	8.22	20.37	25.2
	9		25.2	0

NOTE: On Day 2 Race, battery pack completely drained! *

Motorcycle(thrust) front wheel bearings
Amp-hr meter with LCD readout/telemetry
Two rear wheels
Solarex PVC's
Motorcycle wheels with solid spokes, or
Bicycle wheels with 48 spokes & triple overlay, or Solid composite wheels
Reliable voice activated microphone/two way wireless radio
Digital speedometer & odometer with LCD red-out& telemetry interface.

"Must have" support vehicles

Low-boy, easy access race vehicle trailer
Low maintenance trailer
Large vans for lead & chase vehicles
Short wave radios in all vehicles
Weather channel radio and barometer.

Logistical support

Confirmed motel reservations for each night
"Chuckwagon" equipment with food for noon meals
Port-a-potty
Rain suit for each crew member
Four sets of uniforms for each member
Cellular telephone
Sufficient ten gallon water coolers
Scout entire route prior to and during race.

REFERENCES

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4. J. Starkenberg, Aerodynamic Analysis and Design of a Solar Powered Vehicle Body, Ibid, 1995
5. M. Myllykangas, Structural Design and Analysis of a Solar Powered Vehicle Chassis, Ibid, 1995

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