Performance of Electric and Hybrid Vehicles at the 1995 American Tour de Sol

Spencer Quong, Nicole LeBlanc, Carlos Buitrago, Michael Duoba, and Robert Larsen
Argonne National Laboratory -- Center for Transportation Research

ABSTRACT

Energy consumption and performance data were collected on more than 40 electric and hybrid vehicles during the 1995 American Tour de Sol. At this competition, one electric vehicle drove 229 miles on one charge using nickel metal-hydride batteries. The results obtained from the data show that electric vehicle efficiencies reached 9.07 mi./kWh or 70 equivalent mpg of gasoline when compared to the total energy cycle efficiency of electricity and gasoline. A gasoline-fueled 1995 Geo Metro that drove the same route attained 36.4 mpg.

INTRODUCTION

The 1995 American Tour de Sol (ATdS) was an alternative transportation rally that consisted of more than 40 electric and hybrid-electric vehicles. The rally took place from May 20 to May 27 traveling from Waterbury, Conn., to Portland, Maine. The ATdS was organized by the Northeast Sustainable Energy Association (NESEA) and sponsored by the United States Department of Energy (DOE) and Argonne National Laboratory (ANL).

DOE through ANL provided data acquisition systems (DAS) or kilowatt-hour meters to measure the amount of energy consumed by the vehicles. A gasoline-fueled 1995 Geo Metro provided as a control vehicle was driven by ANL engineers to compare the efficiency of the other vehicles. ANL also arranged technical support by measuring the fuel consumption of the hybrid-electric vehicles (HEVs) and gasoline control vehicle. This paper presents the results obtained from the data collected by NESEA and ANL including vehicle range and energy consumption. It also compares the results to previous competitions and the gasoline control vehicles. Finally, recommendations are made to improve the efficiency of the vehicles.

BACKGROUND

Five different categories of vehicles participated in the ATdS. The Production Category consisted of vehicles from companies that have sold at least five vehicles identical to the one participating in the ATdS. Prototype and converted electric vehicles (EVs) made up the majority of the Commuter Category. These practical, two or more person vehicles were allowed to carry as many batteries as possible, but they had a minimum driving range requirement of 60 miles. Participants in the Solar Racing Category were not given DAS and are not included in this paper. These vehicles received all of their energy from their solar panels and were not allowed to charge from the grid. There were no participants in the Mass Transit Category, but one bus competed in the Production Category. The remaining vehicles were part of the Open Category, which consisted of mopeds, motorcycles, and HEVs. Three hybrid vehicles participated in the 1995 ATdS.[1]

The scoring for the ATdS was based on a rally format. Vehicles scored the most Tour Miles (points) for arriving closest to each leg's "perfect window" of time. The participants were penalized if they were early or late compared to the perfect time. Additional Tour Miles could be earned by completing range laps at the end of certain days. The route usually took place on secondary roads, and drivers had to obey all traffic laws and speed limits. Vehicles that qualified as safe for highway use were allowed to complete longer range laps that took place on highways with speeds up to 65 mph. Daily rally lengths varied between 58 and 73 total miles and range laps were approximately 4 miles for short laps and 22 miles for longer highway laps.

DATA ACQUISITION SYSTEM

The DAS by Cruising Equipment Co. consisted of a kWh meter with an LCD display that monitored battery pack current and voltage. It sampled this information at a frequency of 1.0 kHz and averaged 128 samples for each measurement. The meter integrated the current and power over time to determine the battery capacity (ampere-hours) and battery energy (kilowatt-hours). The voltage across the battery pack was measured through a 100:1 voltage divider. The voltage across a shunt (500 A/50 mV) determined the current. The voltage resolution was 0.5 V, and the current resolution was 1 A. Recent testing on a related Cruising Equipment product showed that the accuracy of the meter was better than 1% of full scale over a wide range of conditions. The meter has the capability to send the data through an RS-232 cable to a laptop computer or a memory module that recorded the real-time data every second.[2] Unfortunately, certain vehicles, such as the Ford Ecostar could not install the DAS on their vehicle due to safety and packaging problems.

RESULTS

The final results of the ATdS are shown in Appendix A. The places are based upon the final Tour Miles, not on efficiency results. The Solectria Corporation took first place in the Production Category with a converted EV Geo Metro and the Commuter Category with a composite EV prototype. The Mt. Everett High School won the Hybrid Category with a propane-fueled pickup truck, and the Schiller Group won the Open Category with an electric scooter. Appendix A also shows the average speed, defined as the total travel time divided by the total distance traveled, for each vehicle during the rally. This value did not account for time lost due to stops or breakdowns, and did not include the legs of the rally that the vehicle did not complete.

EFFICIENCY -- The overall energy consumption of each vehicle was recorded from the DAS after each leg of the rally. This value was compared to the official route mileage, not the actual vehicle mileage, because the accuracy of the vehicles' odometers was questionable. The net efficiency was determined by taking the total miles driven divided by the energy consumed over the entire competition. Legs that vehicles did not complete and range laps were not included in this calculation. The kWh efficiencies of the gasoline and hybrid vehicles were determined by adding the energy content of the fuel consumed to the electrical energy used. No energy cycle conversion losses were included in this calculation. Figure 1 shows the efficiency results of the ATdS.

The efficiency of the Open Category vehicles is higher because these tend to be lightweight, one- and two-passenger vehicles. The passenger EVs in the Production Category used advanced, lightweight drive systems and batteries, and therefore had a higher efficiency than those in the Commuter Category. The efficiencies of the hybrid and gasoline vehicles are lower because of the high energy content of the fuel and inefficiencies of their internal combustion engines. The best efficiency was 43.05 mi./kWh from the Team New England II vehicle. This three-wheel, one person vehicle was very light and efficient, but not very practical. The most efficient commuter EV was Sungo from the New Hampshire Technological Institute. This two-passenger vehicle uses 13.8 kWh (20 hour discharge rate) from lead-acid (PbAc) batteries. Another vehicle of note was a converted 1958 Berkeley EV that only ran one day of the competition, but had an efficiency of 9.26 mi./kWh.

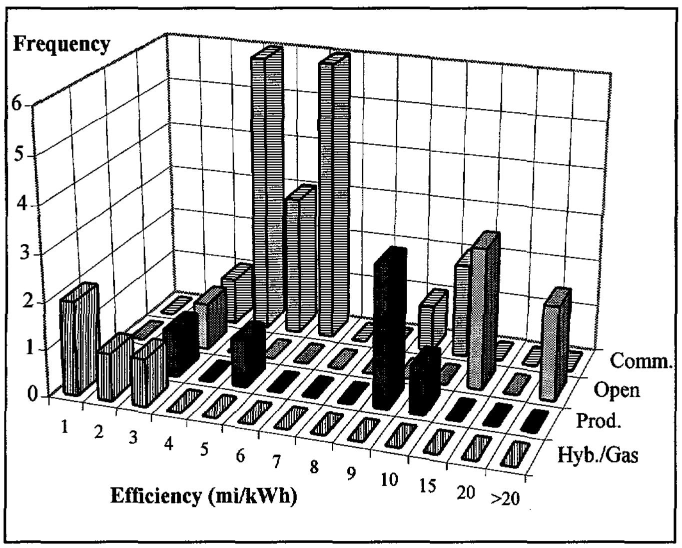

Figure 1: Efficiency Results from the 1995 ATdS

RANGE -- The maximum daily range shown in Figure 2 was the most miles a vehicle drove during a day without charging. This included all legs of the rally and any range laps. The Solectria Sunrise (Figure 3) had the best range of 229 miles. This prototype vehicle with a composite body used 21.6 kWh (20 hour discharge rate) of Ovonic nickel metal-hydride (NiMH) batteries. It can hold four passengers, has a curb weight of 1694 pounds, and has a heating and air-conditioning system. Another impressive performance came from the Bolton High School EV that used 29.3 kWh (20 hour discharge rate) of PbAc batteries and traveled 143 miles on one charge. The vehicles with advanced drive and battery systems, such as the Sunrise and other production vehicles, tended to have better range than other conversions. The HEVs also had a longer range because they could carry a second energy source, gaseous or liquid fuel. The vehicles in the Open Category tended to have smaller battery packs and, therefore, less range than the other vehicles. Appendix A shows the net efficiency and maximum daily range for each vehicle in the ATdS.

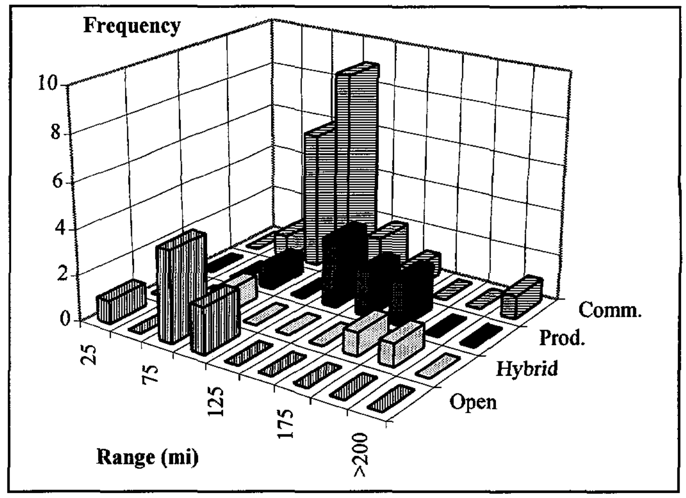

Figure 2: Maximum Daily Range Results from the ATdS

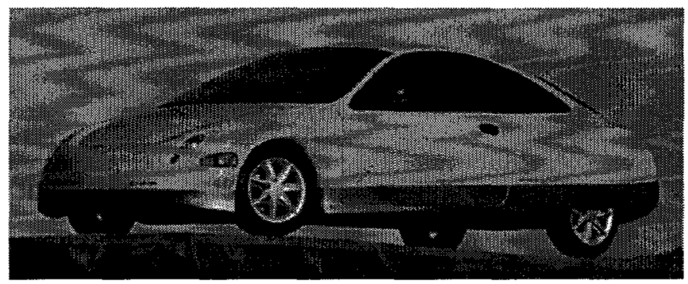

Figure 3: Solectria Sunrise

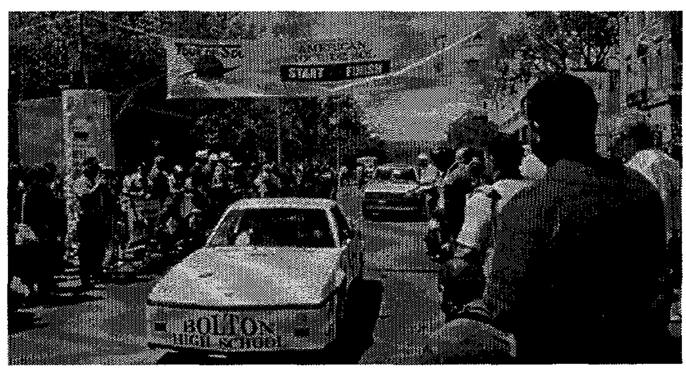

Figure 4: Bolton High School

DISCUSSION

IMPROVEMENTS IN THE ATdS -- The 1995 ATdS is the seventh running of the competition. Many improvements have been made in EV technology that have been reflected in the performance of the vehicles at the ATdS. One vehicle that has competed for several years is the Solectria Force -- a Geo Metro conversion with PbAc batteries. This vehicle has improved its range by almost 95% since 1992, as shown in Figure 5. One important note is that the Force had only a one-mile increase in maximum range between 1994 and 1995, which may show a limitation on advancements with current technology and batteries. The maximum daily range record of the ATdS has also increased from 100 to 229 miles between 1992 and 1995.

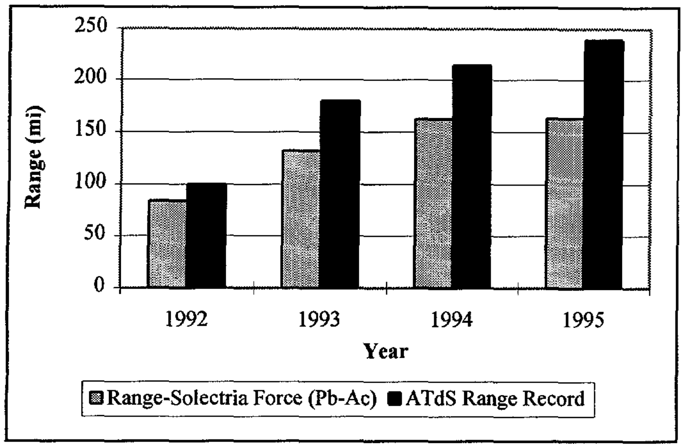

Figure 5: Improvements in Vehicle Range at the ATdS

Vehicle efficiencies have only been monitored during the rally for the past two years at the ATdS. Figure 6 below shows the efficiency improvements in the Solectria Force with traditional PbAc batteries and the average efficiencies of the Commuter, Production, and Open Categories. Although the vehicles did not travel on the same route in 1994 and 1995, there was a general increase in efficiency over the two years.

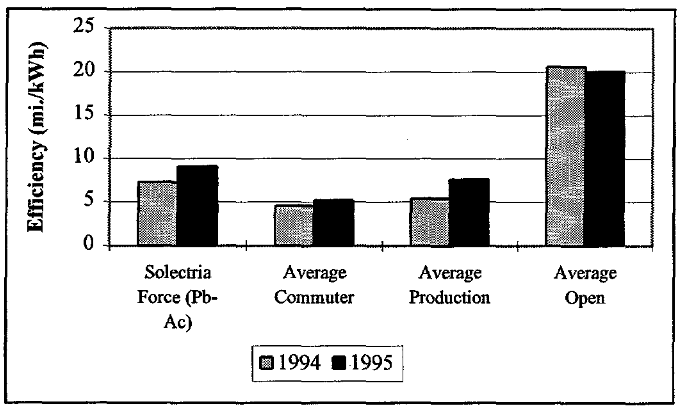

Figure 6: Improvements in Vehicle Efficiency at the ATdS

COMPARISON TO GASOLINE VEHICLES -- As stated earlier, a gasoline-fueled 1995 Geo Metro drove the same route as the EVs. Figure 7 shows the equivalent miles per gallon (mpg) of gasoline for the gasoline vehicle and similar EVs. The equivalent mpg compares the total energy cycle efficiency of both vehicles. This is done in Reference 3 by Wang et al. by comparing the efficiencies of converting crude petroleum to electricity (well to plug), and crude petroleum to gasoline (well to pump). The ratio of the electricity efficiency to gasoline efficiency is 0.321.[3] A battery efficiency of 80% and an electric charging efficiency of 90% was included to achieve a final energy cycle efficiency ratio of 0.231. A fuel energy content of 33.4 kWh/gallon, typical of regular unleaded gasoline, was used.

The results in Figure 7 show that the Solectria Force (a Geo Metro EV Conversion) with traditional deep-cycle PbAc batteries was 92.5% more efficient than the gasoline control vehicle. The comparison of a gasoline and electric Geo Metro, emphasizes the efficiency improvements with an EV. The efficiencies of other Forces with advanced Horizon PbAc and nickel-cadmium (NiCd) batteries, and of the Solectria Sunrise, were also included. Appendix A also shows the equivalent mpg of all the vehicles at the ATdS using the total energy cycle efficiency as discussed above.

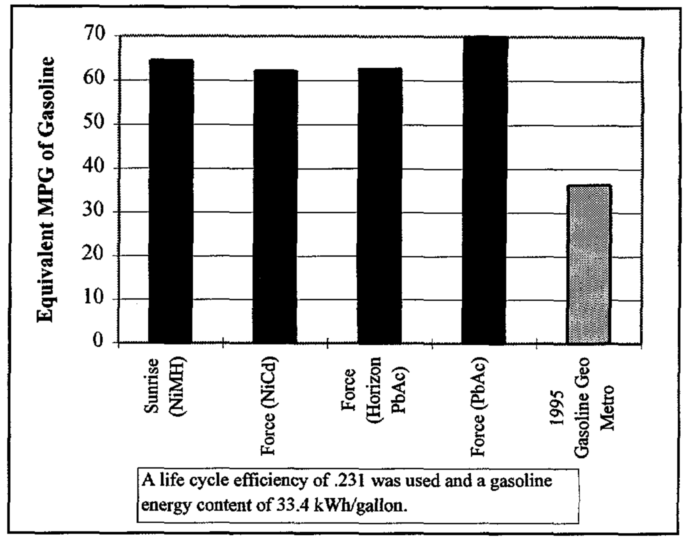

Figure 7: Equivalent Efficiency of Vehicles at the ATdS

EFFICIENCY IS THE KEY -- One of the key technical and economic goal of EVs is improved energy efficiency. Before the start of the 1994 ATdS, several EVs and three related gasoline control vehicles were tested on a dynamometer over a highly transient driving cycle depicting typical city driving. The results from the testing showed that EVs were only slightly more efficient than gasoline vehicles when comparing the total energy cycle efficiency.[4] In contrast, in 1995 EVs were almost twice as efficient as the gasoline control vehicle during the rally.

Why was there such a dramatic increase in efficiency between the two years? One of the main reasons was the conditions of the tests. In 1994, the dynamometer testing was done in a controlled environment, using the same driver and a standard driving cycle (Federal Urban Driving Schedule). During the 1995 ATdS, the data were collected during the road rally, where conditions, such as speed, vary and vehicles are driven much more efficiently.

The data collected at the 1994 ATdS showed that vehicles are driven much more efficiently during the rally competition. Therefore, reducing the number and amount of accelerations and taking full advantage of regenerative braking will significantly increase vehicle efficiency. Other evidence is shown in Figure 7. The Solectria Force with traditional PbAc batteries was the most efficient Solectria Force at the 1995 ATdS (9.07 mi./kWh). The two other Solectria Forces with advanced Horizon PbAc (8.13 mi./kWh) and NiCd (8.07 mi./kWh) batteries were lighter vehicles, but they still had lower efficiencies. The driver of the Force with standard PbAc was driving efficiently, sacrificing his rally times for slower speeds and energy consumption. The Force with NiCd batteries, the winner of the Production class, was driven faster and used more energy. Also, the drivers of the Force with Horizon batteries were inexperienced with EVs and may have not been able to show the vehicle's peak efficiency.

Weight is an equally important factor influencing efficiency. For example, the most efficient Commuter Category vehicle, Sungo, had an efficiency of 9.54 mi./kWh. The Sungo used traditional PbAc batteries and a DC Brushless drive system. In contrast, the Solectria Sunrise with NiMH batteries and an AC drive system had a lower efficiency at 8.36 mi./kWh. The Sunrise was a heavier, four-passenger vehicle compared to the lightweight Sungo. (Unfortunately, the scales used to measure the vehicle weights at the ATdS were inaccurate, so no direct comparison of vehicle weights is available.)

CONCLUSION

The 1995 ATdS showed significant improvements in EV performance. The data gathered at the competition showed that, during the road rally, EVs were almost twice as efficient as a high fuel economy gasoline vehicle. Improvements in efficiency could be attributed not only to vehicle technology, but also to driving style and weight reduction. Plans for the 1996 ATdS include more dynamometer testing and collection of energy consumption data during the road rally.

ACKNOWLEDGMENTS

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APPENDIX A: RESULTS FROM THE 1995 AMERICAN TOUR DE SOL

Place	Class	#	Team	Vehicle	Average Speed (mph)	Range (mi.)	Efficiency (mi./kWh)	Equivalent mpg
1	Comm	63	Boston Edison/NAVC	Solectria Sunrise	30.65	229	8.36	64.56
2	Comm	61	Bolton HS	Solar Bolt	29.67	143	5.57	43.02
3	Comm	66	Genesis Team	Genesis I	29.81	104	3.73	28.79
4	Comm	64	CSERT-NVCTC	Kineticar II	27.74	88	3.72	28.69
5	Comm	78	Sofix Design	Sofix Sedan	25.04	104	5.90	45.51
6	Comm	81	Wooster's Charge	Sparky	27.12	96	4.32	33.31
7	Comm	60	Blue Sky Club	Millenium Falcon	25.69	96	3.40	26.27
8	Comm	74	Parkland HS/Lehigh Co VTS	Lightning Volt	21.96	76	3.83	29.53
9	Comm	70	Fall Mountain	Sun-Bunny	27.09	91	4.31	33.26
10	Comm	72	NHTI	Sungo	24.27	73	9.54	73.67
11	Comm	80	1000 Islands Sec. School	Brock Electruck	22.79	80	2.22	17.16
12	Comm	53	EVelfa Electra Auto	Elfa Electra	22.18	71	5.21	40.25
13	Comm	76	RHAM Science and Tech.	RHAM Rod	28.07	96	3.96	30.54
14	Comm	69	Fulmine	Hyundia- Excel	21.23	80	3.72	28.70
15	Comm	65	Falmouth	Electric Hare	21.14	80	5.74	44.29
16	Comm	71	Minuteman Science-Tech	S-15 Truck	23.33	62		
17	Comm	75	Polytech Chargers	KA1000	19.71	68	5.57	43.02
18	Comm	67	GLEAA/GLEAN	ZeeVee88	23.78	51	5.61	43.31
19	Comm	73	Orr	Electric Fiero	27.19	29	4.69	36.18
20	Comm	79	Team New England	1958 Berkeley	26.25	58	9.26	71.47
21	Comm	68	Greenwich	Solar Flair I		0		
1	Hyb	96	Mt. Everett	Project e-	28.19	186	0.51	3.92
2	Hyb	3	Cornell Univ.	Tempest	26.69	151	0.84	6.49
3	Hyb	95	Dartmouth	Ecovox	17.88	72	2.22	17.16
1	Open	49	Schiller Group	ERANGE	19.00	80	22.68	175.11
2	Open	92	WE'RE It	Sunpacer	19.29	73	11.28	87.09
3	Open	94	Tom Hopper	Hopper EV	21.91	73	10.63	82.08
4	Open/Gas	10	Gasoline Control Vehicle	1995 Geo Metro	32.03	73	1.09	36.37
5	Open	28	Team New England	TNE II	25.88	95	43.05	332.29
6	Open	89	CCSU	Envirocycle III	16.31	61	12.52	96.63
7	Open	91	ZAP Rotator	Wild Cherry	10.12	56	2.49	19.19
8	Open	93	Cato-Meridian HS	Helios the Heron		16		
1	Prod	56	Virginia Power	Solectria Force	30.52	175	8.07	62.30
2	Prod	55	NE Utilities	Ford Ecostar	31.70	163		
3	Prod	7	EVermont/NAVC	Nordic Challenger	28.49	128	9.07	70.02
4	Prod	50	Conn EV/NAVC	Solectria Horizon	29.38	128	8.13	62.79
5	Prod	51	CT EV Project/EWS/NAVC	Solectria Force	29.46	102	8.03	61.96
6	Prod	62	NAVC/Hanscom AFB	Solectria E-10	29.90	111	4.60	35.52
7	Prod	90	Zap	Power Rotator	21.23	102		
8	Prod	54	NE Power Service	US Electricar Bus	14.49	73	2.81	21.71

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