EPA-AA-TAEB 75-3

Performance of the Electrosport Electric Vehicle

June 1974

Technology Assessment and Evaluation Branch
Emission Control Technology Division
Office of Mobile Source Air Pollution Control
Environmental Protection Agency

Background

The Electric Fuel Propulsion (EFP) Company of Ferndale, Michigan, has been converting conventionally powered vehicles to electric power. EFP does the required design work, fabricates system components as necessary and installs the system in a vehicle.

The Special Vehicle Program Branch of the Advanced Automotive Power Systems Development Division contracted with EFP (contract #EH SH-71-008) for the use of a prototype vehicle to evaluate its performance. The test of the vehicle reported herein was conducted over a one-year period from August 1972 to July 1973.

The performance tests were conducted by the Test and Evaluation Branch of the Emission Control Technology Division in support of the Special Vehicle Programs Branch.

Vehicle Description

The car tested for this project was an American Motors (AMC) Hornet station wagon modified for electric operation by EFP. The engine usually installed in this vehicle is either a 258 CID 6-cylinder or a 360 CID V-8 gasoline fueled internal combustion engine.

The EFP designed electric power system installed in the vehicle consists of a 20 hp Porter 144 volt D.C. motor, control circuits, and twenty-four 6-volt lead-acid batteries in series. The motor uses a separately excited shunt field and is installed in the standard engine position. The batteries were placed in the front in the engine compartment, at the rear under the floor, and under the rear seat. The standard vehicle manual transmission (with ratios of 2.548, 1.558, and 1:1) and rear axle (4.44:1 ratio) were used. Additional control circuits protect the motor and step down the battery voltage to the vehicle operating requirements. Power is controlled by the standard foot pedal. Battery charging used 220 V and takes about 6 hours to fully recharge the batteries.

The curb weight of the car in stock condition is 2830 pounds with the 6-cylinder engine and 3060 pounds with the V-8 engine. The electric-powered vehicle weighed 5260 pounds, due to the battery weight. Vehicle instrumentation consisted of an amp-hour meter, battery and motor volt and amp meters, motor speed and motor pyrometer (temperature). All lab testing was done at an inertia weight of 5860 pounds to duplicate road test weights.

Test Program

The car arrived at the Ann Arbor laboratory on August 18, 1972. After initial checkout and familiarization, the car was taken to the Dana test track at Ottawa, Michigan, for performance testing. Due to vehicle problems these tests were not completed until January. Other EFP commitments for the car prevented completion of laboratory testing until July 1973. The vehicle was tested for acceleration, steady state range, transient range, power, performance at partial battery charge, and energy economy.

Road performance testing was done by Dana at their track under an EPA contract. The Dana test track is a 1 3/4-mile concrete oval with a design speed of 60 mph. The vehicle speed and mileage were measured with a calibrated 5th wheel. Vehicle braking distance was recorded by using detonators to mark start and stop of braking. For performance at partial charge, the vehicle's amp-hour meter was used to indicate state of charge. Recharge energy was measured with a three-phase power meter connected in series with the battery charger.

Vehicle acceleration runs were done with the batteries both fully charged and 80% discharged. Maximum speed capability mileage tests were a repetitive cycle using the motor current-time limits to set vehicle speed.

For transient range the vehicle steady state power requirements were duplicated on a chassis dynamometer. The Federal Driving Cycle was used and end of range determined when the vehicle could no longer follow the velocity profile.

Results and Discussion

Results of the performance tests are detailed in the Appendix for both the road and dynamometer tests, and are summarized below. The average of three tests at each speed gave these results:

Vehicle Range at Constant Speed

MPH	MILES	RECHARGE K-W HOURS
28.8	64.9	21.5
42.8	47.1	18.2
60.7	34.0	15.2

These results are plotted as energy economy and distance vs. speed in Figures 1 and 2 respectively. The K-W hour values for these tests are suspect. A comparison with previous tests (Ref.1) shows that previously the vehicle was able to travel about 40% further, although it consumed about 30% more kilowatt-hours per miles.

For the transient range tests both the standard dynamometer road load and test road load data (Table I) were used. The results are:

VEHICLE RANGE ON FEDERAL DRIVING CYCLE

Date	Mileage
2-7*	30.0
2-12*	37.5
2-20*	25.7
6-21*	22.6
7-3**	25.0

*Standard road load for 5500 lb. vehicle is 13.9 hp at 50 mph, per Federal Test Procedure

**Vehicle road load curve

To obtain vehicle range over a transient driving cycle it is important to use an accurate road load curve, since a battery's energy capacity is strongly dependent on its discharge rate. Therefore, the EFP vehicle's actual road load horsepower was also used for a range test on July 3. Results were comparable to the two previous tests. This road load curve and the actual dynamometer curve are listed in Table I. They are in reasonably close agreement.

TABLE I
Vehicle Horsepower

MPH (vehicle)	HP Delivered	HP Required	HP dyno
10	3.4	2.4	2.0
20	6.4	5.5	4.9
30	8.0	9.7	9.3
40	12.9	15.5	15.6
50	21.1	23.7	22.8

Delivered HP is calculated from the motor current and voltage requirements during steady state road tests. HP dyno is the horsepower delivered to the dynamometer with corrections made for rear wheel and drivetrain losses. HP required is an estimated value for the vehicle weight and frontal area.

The acceleration tests (Figure 3) showed a marked increase in acceleration times for the 80% discharged battery compared to the fully-charged condition. The car took about twice as long to reach a given speed. These results do not reflect the best performance the vehicle is capable of due to difficulties experienced in the upshifting of the manual transmission. The difficulty may have been worn transmission synchronizers. No attempt was made to repair the transmission.

When operated at maximum speed the car went 53.6 miles at an average speed of 35.7 mph. In braking tests the car stopped in 75 ft. at 40 mph and in 173 ft. at 60 mph. Maximum speed on a 5% grade was 40 mph when 65% charged and 30 mph when 35% charged.

The vehicle recharge energy was measured with a standard building kilowatt hour meter. Apparently it was unsuitable for accurately measuring the charging energy since the batteries and charger present an unusual load and power factor to it. An indication of this is the road test of June 25. The power used by the motor, calculated over the entire route, is 12.8 KW-hrs. Yet the indicated recharge energy of 14 KW-hrs infers a charge/discharge efficiency of 91%. This is considerably higher than the 70% efficiency that could reasonably be expected from experience with other battery systems. Also, when the charger was adjusted for low current draws (15 amps at 200 volts) the meter would indicate no energy consumption even after several hours.

During the vehicle dynamometer testing there were considerable odors during heavy load conditions. This was probably either hot insulation or gases from the rapidly discharging batteries. Momentary power cutbacks also occurred, probably due to the motor thermal protective device. The vehicle also seemed to operate at times in an anamolous fashion - two widely varying power consumptions under identical conditions. The tests on June 25 showed 40% changes in power consumption from lap to lap at both 20 and 30 mph. The vehicle would operate at a certain level of current and voltage for a lap and then suddenly change 40% and hold the new setting, while the vehicle neither accelerated nor decelerated.

Overall vehicle handling was poor. The car weighed 65% more than the standard car and most of the additional weight was at the front and rear of the car. Therefore, steering was extremely poor. Also, the required oversize springs were not tuned to the vehicle suspension.

Prior to EPA testing, EFP conducted extensive tests at Dana. These tests (Ref. 1) were conducted in accordance with the

"Specifications for Battery Powered Electric Multi-purpose Work Vehicles" of the Electric Vehicle Council, February 1972 (Ref. 2). These specifications are for battery powered, multi-purpose work vehicles for use by the electric utility industry, public agencies, and private corporations. In general the vehicle easily met the performance requirements. However, during the testing by EPA, vehicle performance did not meet these same standards. The only major vehicle change between the EFP and EPA tests was a complete battery change after the start of EPA's track testing, which should have improved performance.

These tests of the electric vehicle showed that the car was capable of light duty city-suburban use. However, considerable improvements in handling would be necessary before the vehicle was safe to drive.

REFERENCES

1. William F. Volk, "Performance Tests of Electric Fuel Propulsions Electrosport Electric Vehicle," Dana Laboratory Report #599 for Electric Fuel Propulsion.

2. "Specifications for Battery Powered Electric Multi-purpose Work Vehicles," February 1972, Electric Vehicle Council.

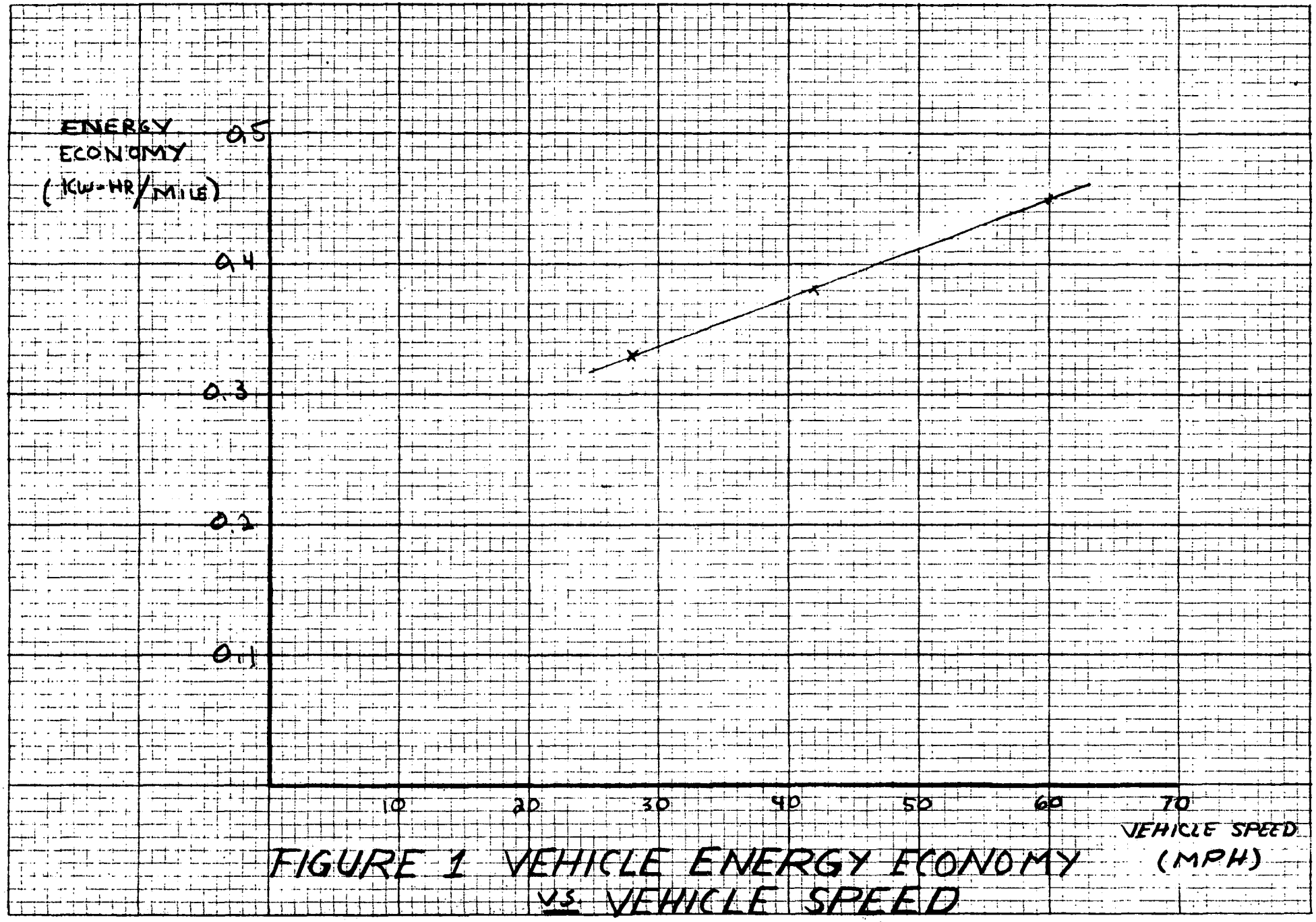

FIGURE 1 VEHICLE ENERGY ECONOMY VS. VEHICLE SPEED

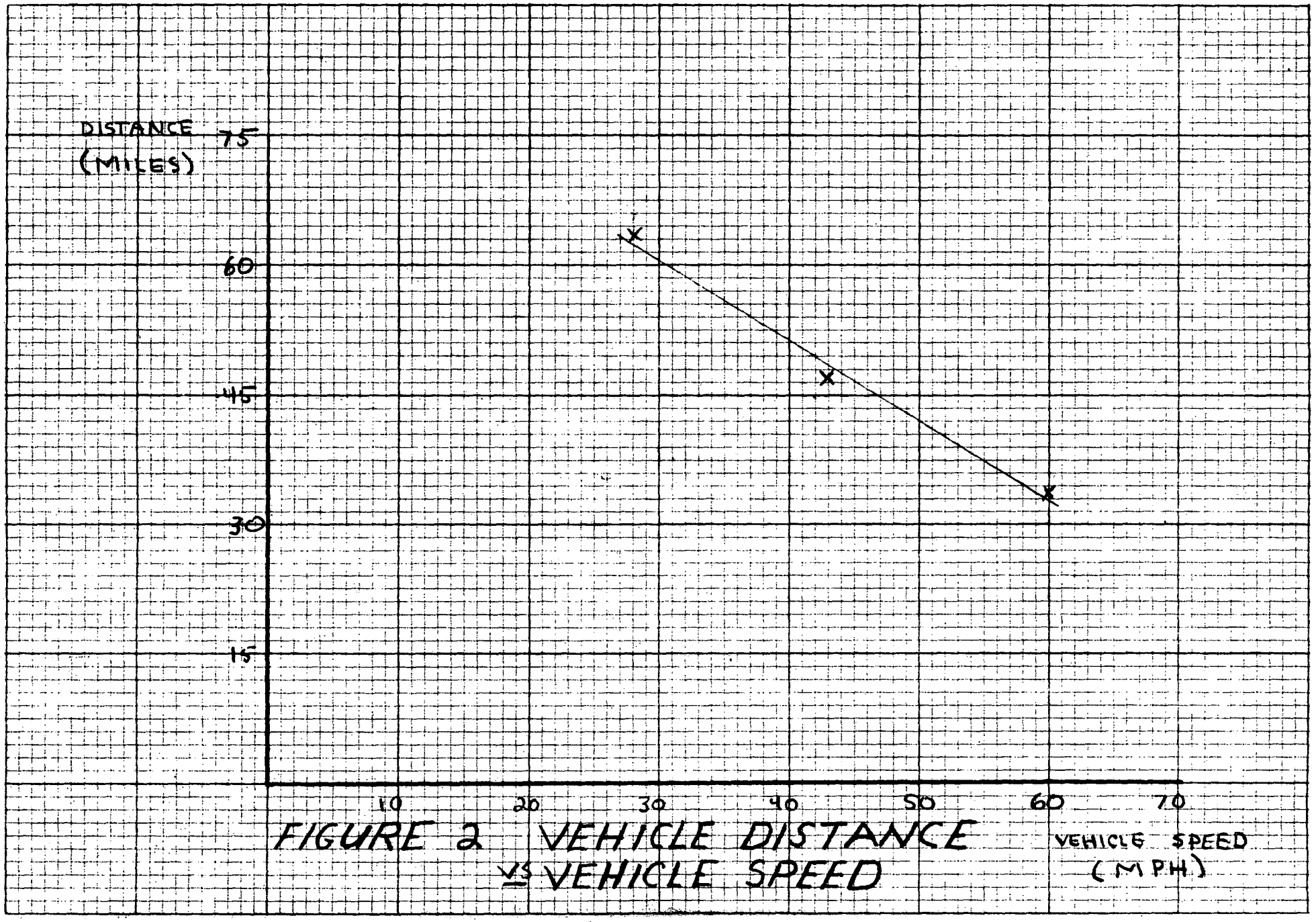

FIGURE 2 VEHICLE DISTANCE VS VEHICLE SPEED

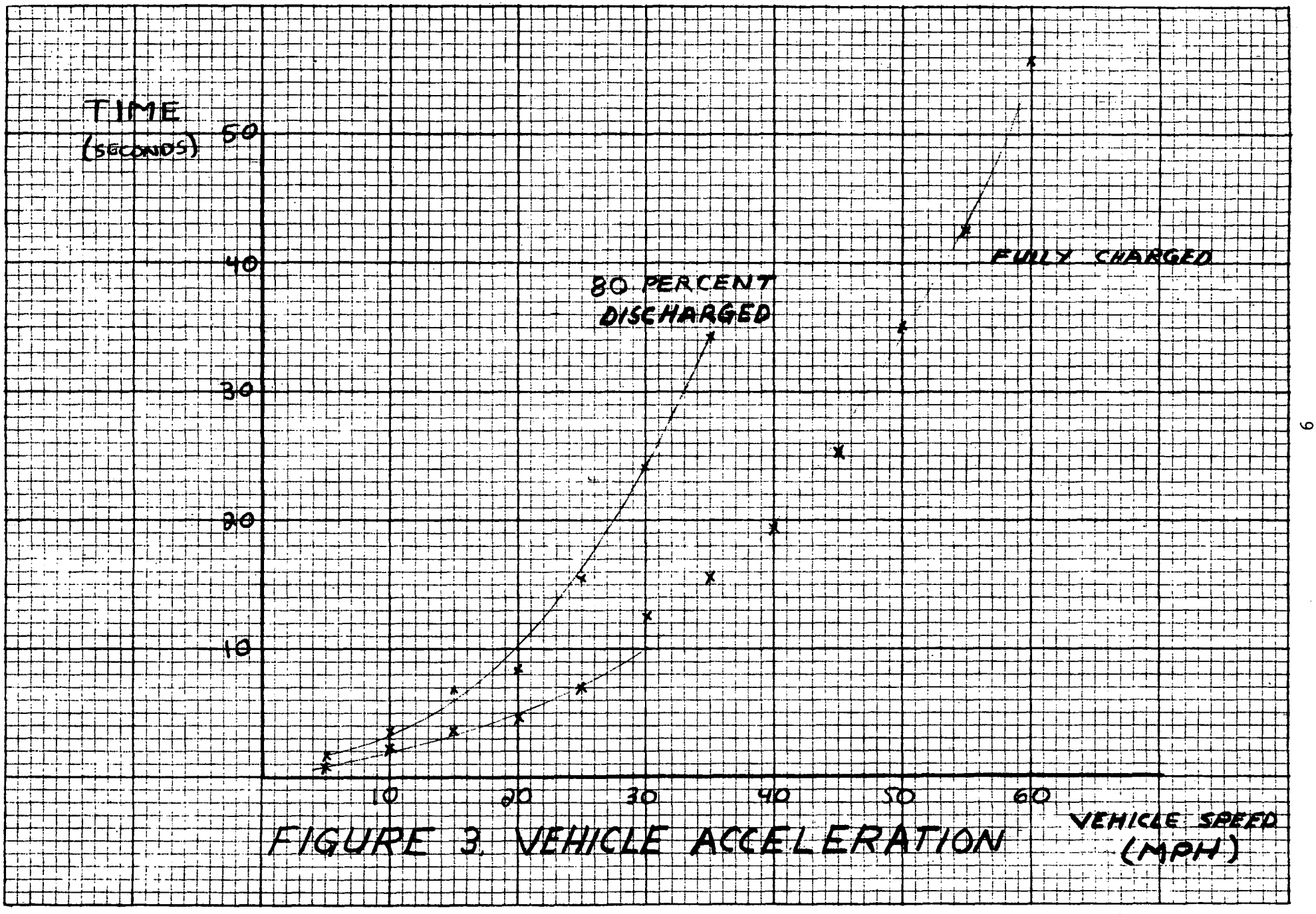

FIGURE 3. VEHICLE ACCELERATION

APPENDIX

EFP ELECTROSPORT

To Drive:

Start in First Gear, drive in First Gear between 0 and 25 mph.

Drive in Second Gear between 26 and 45 mph.

Drive in Third Gear over 45 mph.

Manual Transmission - Use clutch to change gears.

Current Limit on DC Motor:

150 amps continuous
200 amps for 10 minutes
300 amps for 5 minutes

Starting surge currents are as high as 1000 amps.

Recharging the Batteries:

Maximum Charging Potential 175 volts
Maximum Charging Current 200 amps

Electrosport
February 20, 1973

Miles*	Battery Voltage Start	Stop	Indicated amp hours in battery	Battery Temp.
7.45	155	142	225	74°F
7.35	142	140		
7.35	140	140		
3.55**	140	139	85	90°F

Net 25.7 miles

*Federal Driving Cycle
**Loss in acceleration at 360 seconds, test was 505 seconds duration.

Mileage Electrosport
June 21, 1973

Battery chg.(corrected) 1265 — Start
Battery temp. 75°F
Amp-hours 0
Mileage 0000.0
Motor case temp. (end of run)
Tire pressure 45 psi
Inertia wt. 5500 lbs.

Battery chg.(corrected) 1240 — End 1st LA-4
Battery temp. 80°F
Amp-hrs. 35
Mileage 7.85
Motor case temp. 120°F
Net mileage 7.85 miles

Battery chg.(corrected) 1197 — End 2nd LA-4
Battery temp. 85°F
Amp-hrs. 67.5
Mileage 15.55
Motor case temp. 145°F
Net mileage 7.7 miles

Battery chg.(corrected) 1134 — End 3rd LA-4
Battery temp. 90°F
Amp-hrs 112.5
Mileage 22.55
Motor case temp. 160°F
Net Mileage 7 miles
Unable to keep up with road speed trace

recharge 13.4 kw hr (this measurement is in error)

TABLE II

CONSTANT SPEED POWER REQUIREMENTS

	Road Data June 25							Dynamometer Data			
MPH Indicated	MPH Actual	Battery Amps	Battery Volts	Watts	HP at motor	HP est*	Dyno ** HP cal.	Dyno Torque cal.	Dyno Torque Set	Dyno HP Set	HP *** Dyno
10	10.0	97	26	2522	3.4	2.4	1.3	94	65	.9	2.0
20	20.5	100	48	4800	6.4	5.5	3.1	113	90	2.5	4.9
30	31.1	112	53	5936	8.0	9.7	6.0	146	135	5.6	9.3
35	36.3					12.3	8.1	167	162	7.9	12.1
40	41.7	127	76	9652	12.9	15.5	10.7	192	195	10.8	15.6
45	47.0					19.3	13.8	220	213	13.3	18.8
50	52.3	197	80	15700	21.1	23.7	17.6	252	237	16.5	22.8
55	55.8					28.9	22.2	288	264	20.3	27.0
60	55.8	237	100	23700	31.8						
66				34800	46.7						

HP = TV/750 T = dyno torque, V = mph

*HP estimated $= \frac{V}{375}\left[(.015)(5840) + (.0015)(20)\ V^2\right]$

**Dyno HP cal. $= \frac{V}{375}\left[(.015)(2720) + (.0015)(20)\ V^2\right]$

***Includes rear wheel losses

HP (at motor) does not include driveline efficiency (95%)
Weight = 5840 lbs.
Frontal area: 20 sq. ft.

Road Loads - Electrosport

June 25, 1973, at Dana Test Track
Tire pressure 33 psi
3 people in vehicle
total mileage 44 miles
26 laps of 1.75 miles
recharge 14.0 kw hr (this measurement is in error)

0-25 1st gear
25-45 2nd gear
45 up 3rd gear

Test Series #1

Battery specific gravity 1275 (corrected) at start
Battery specific gravity 1247 (corrected) at end
Battery temperature 80°F at start
Battery temperature 85°F at end
Battery amp-hours 0 at start, 25 at end
Temperature 82°F, wind SE 6-8 knots

Speedometer MPH	Direction	DC Amps	DC Volts	RPM	Motor Temp.
10	W	90-95	25-26	1250	80°F
10	E	100	27.5	1350	85°F
20	W	100	47.5	2350	87°F
20	E	100	48	2325	87°F
30	W	105	56	2075	89°F
30*	E	155	60	2150	89°F
30	W	105	50	---	---
30	E	120	56	2100	90°F
30	W	101	51	2150	92°F
40	E	135	79	2775	92°F
40	W	120	73	2900	92°F
50	E	200	81	2300	93°F
50	W	195	80	2450	95°F
60	E	245	100	2650	95°F
60	W	230	99	2700	95°F

Test Series #2

Battery specific gravity 1247 (corrected) at start
Battery specific gravity 1193 (corrected) at end
Battery temperature 85°F at start
Battery temperature 87°F at end
Battery Amp-hours 25 at start, 81 at end
Temperature 86°F, wind, east 4 knots at end

10	E	91	28.5	1850(?)	103°F
10	W	95	27.5	1350	107°F
10	E	93	27.2	1350	105°F
20*	W	59	45	2350	103°F
20*	E	42	44	2300	100°F
20	W	95	45	2350	100°F
20*	E	78	39	2300	100°F
20	E	95	41	2450	100°F

*Anomalous data points

Speed-ometer MPH	Direction	DC Amps	DC Volts	RPM	Motor Temp.
30	W	150	59	2150	102°F
30	E	125	55	2175	99°F
40	W	133	70.5	2700	99°F
40	E	155	77	2800	97°F
50	W	225	80	2300	95°F
50	W	236	81	2325	98°F
50	E	260	84	2300	97°F
60	W	240	95	2700	97°F
60	E	240	93	2675	97°F
63	W	330	109	2900	---
66	E	305	118	3000	---
66	W	295	114	3000	97°F

Test Series #3

Battery specific gravity 1193 (corrected) at start
Battery specific gravity 1156 (corrected) at end
Battery temperature 87°F at start
Battery Temperature 93°F at end
Battery AMP-Hours 81 at start, 108 at end
Temperature 84°F wind East 8-12 knots at end

10	E	90	26.5	1350	125°F
10	W	83	25	1350	125°F
20	E	85	45	2300	115°F
20	W	75	43	2300	115°F
30	E	122	55	2150	113°F
30(29)	W	102	47	2180	108°F
40	E	173	85	2825	108°F
40	W	135	74	2800	105°F
50	E	230	83	2300	105°F
50	W	215	79	2300	105°F
52	E	240	84	2375	105°F
51	W	223	79	2375	105°F

Test Series #4

2 laps maximum speed attainable 45 and 35 mph
Battery specific gravity 1156 (corrected) at start
Battery specific gravity 1125 (corrected) at end
Battery temperature 93°F at start
Battery temperature at end
Battery AMP-Hours 108 at start, 125 at end

Electrosport
June 28, 1973
Tire pressure 45 psi
Recharge 3 kw hr
Battery specific gravity 1280 at start
Battery temperature 76°F at start
Amp hour at start 0

0-25 mph 1st gear
25-45 mph 2nd gear
45 up mph 3rd gear

vehicle mph	dyno mph	batt volts	batt amps	motor volts	motor amps	torque ft/lbs
10	10.5	146	26	29.5	97	30
20	21	146	46	50	98	56
30	31.5	146	55	53.5	112	24
40	42.0	143	85/70	73/68	125	54/22
50	53.0	140	123	76	195	92
60	63.5	135	195	98	235	164
amp hour 15						
10	10.5	146	50	39.5	93	50
20	21	141	100(?)	70	98	65
30	31.5	146	58	51	110	45
40	42	144	86	71	130	70
50	52.5	139	137	77.5	193	119
60	63.5	133	224	100	220	202
Battery specific gravity 1263 Battery temperature 76°F Amp hour 30						
10	10.5	147	30	32	104	85
20	21	145	47	53	102	175
30	31.5	142	76	61	130	100-105
40	42.0	140	115	82	140	138
50	52.5	134	180	86	213	199
60	63.5	131	218	99	215	194
Battery Specific gravity 1244 Battery temperature 78°F Amp hour 48						

$$HP = \frac{\text{Torque (ft. lbs.) X Velocity (MPH)}}{750}$$

Electrosport
July 2, 1973
Tire pressure 45 psi
Battery specific gravity 1275
recharge 4 kw hr
battery temperature 75°F
amp hours 0

Level Road Load

vehicle mph	dyno mph	batt. volts	batt. amps	motor volts	motor amps	torque ft/lbs.
10	10.5	147	62	30.5	102	48-50
20	20.5	146	52	57	115	90
30	31	143	95	64	162	146
40	41	140	135	85	178	188
50	52	134	233	88-91	275	261
60	61.5	130	270	98	285	271

amp hours 21

Road load with 5% grade

10	10	142	87	47	238	600
20	19.5	136	190	79	250	640
30	30	126	300+	88	385	690
40	38.5	118	300+	116	410	777

battery specific gravity 1225
battery temperature 85°F
amp hours 43

Level road load

10	10.5	147	51	27	98	48
20	20	145	49	48	111	81
30	31	140.5	90	64	172	150
40	41	136	144	86.5	200	200
50	53	126	260	93	315	277
60	64	---			375	350

Road load with 5% grade

10	10	135	105	59	240	590
20	19.5	123	185	79	250	634
30	31	90	---	88	390	699

battery specific gravity 1190
battery temperature 90°F
amp hours 75
Level road load

10	10	142	52	26	90	46
20	20.2	140	48	50	100	89
30	31	124	83	63	152	147

Electrosport, July 2, 1973 continued:

40	40.5	112	153	82	170	190
40+	42.5	85.5	200	88	190	207

battery specific gravity 1165
battery temperature 92°F
amp hours 83

$$HP = \frac{\text{Torque (ft. lbs.) X Velocity (MPH)}}{750}$$

Mileage Electrosport
July 3, 1973

Battery chg. (corrected) 1277 Start
Battery temp. 72°F
Amp hours recharge 12 kw hr
Mileage 0000.0
Motor case temp. 72°F
Tire pressure 45 psi
Inertia wt. 5500 lbs.

Battery chg. (corrected) 1242 End 1st LA-4
Battery temp. 82°F
Amp hours 25
Mileage 7.8
Motor case temp.
Net mileage 7.85 miles

Battery chg. (corrected) 1215 End 2nd LA-4
Battery temp. 90°F
Amp hours 60
Mileage 15.5
Motor case temp. 140°F
Net mileage 7.35 miles

Battery chg. (corrected) 1163 End 3rd LA-4
Battery temp. 100°F
Amp hours 103
Mileage 22.4
Motor case temp. 160°F
Net mileage 7.25 miles
Unable to keep up with road speed trace at end 10 min.

Battery chg. (corrected) 1150 End 4th LA-4
Battery temp. 95°F
Amp hours 115
Mileage 25.0
Motor case temp. 155°F
Net mileage 2.6 miles
Maximum speed 41 mph - 57 mph desired
28 mph - 35 mph desired
20 mph - 30 mph desired
Test terminated after 440 seconds