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16 Abstract

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The Electric and Hybrid Vehicle Program was conducted under the guidance of the then Energy Research and Development Administration (ERDA), now part of the Department of Energy.

BASELINE TESTS OF THE

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SUMMARY

The Battronic Minivan, an electric passenger vehicle manufactured by the Battronic Truck Corp., a Division of Boyertown Auto Body Works, was tested at the Dynamic Science Test Track in Phoenix, Arizona, between February 5 and March 6, 1977. The tests are part of an Energy Research and Development Administration (ERDA) project to characterize the state-of-the-art of electric vehicles. The Battronic vehicle performance test results are presented in this report.

The Minivan is a two-passenger van with sliding side entry doors and a large rear door. It is powered by a two-module, 112-volt semi-industrial battery through an SCR direct-current (DC) chopper controller with bypass contactors. The motor is a 31-kilowatt (42-hp) series-wound DC traction motor. The braking system is a conventional hydraulic braking system. Regenerative braking was not provided.

All tests were run at the gross vehicle weight of 2860 kilograms (6300 lbm). The results of the tests are as follows:

Test condition (constant speed or driving schedule)		Type of test						
		Range		Road power, kW	Road energy		Indicated energy consumption	
km/h	mph	km	mile		MJ/km	kWh/mile	MJ/km	kWh/mile
Low gear								
40	25	105.7	65.7	5.9	0.53	0.24	1.55	0.69
60	37	82.3	51.2	12.9	.77	.35	2.19	.98
High gear								
72	45	54.0	33.6	18.3	0.91	0.41	3.21	1.43
84	52	35.4	22.0	----	----	----	4.03	1.80
B		79.5	49.4	----	----	----	2.45	1.10
C		63.7	39.6	----	----	----	2.92	1.30

The Minivan was able to accelerate from 0 to 32 kilometers per hour (0 to 20 mph) in 7 seconds and from 0 to 48 kilometers per hour (0 to 30 mph) in 11 seconds. The gradeability limit was 50 percent for 1 to 2 seconds only. The duration was limited because the 400-ampere motor protection fuse failed due to current overload.

The efficiency of the battery charger was measured and found to be 85 to 95 percent over a complete charge cycle.

INTRODUCTION

The vehicle tests and the data presented in this report are in support of Public Law 94-413 enacted by Congress on September 17, 1976. The law requires the Energy Research and Development Administration (ERDA) to develop data characterizing the state-of-the-art of electric and hybrid vehicles. The data so developed are to serve as a baseline (1) to compare improvements in electric and hybrid vehicle technologies, (2) to assist in establishing performance standards for electric and hybrid vehicles, and (3) to help guide future research and development activities.

The National Aeronautics and Space Administration (NASA), under the direction of the Electric and Hybrid Research, Development, and Demonstration Office of the Division of Transportation Energy Conservation of ERDA, has conducted track tests of electric vehicles to measure their performance characteristics and vehicle component efficiencies. The tests were conducted according to ERDA Electric and Hybrid Vehicle Test and Evaluation Procedure, described in appendix E of reference 1. This procedure is based on the Society of Automotive Engineers (SAE) J227a procedure (ref. 2). Seventeen electric vehicles have been tested under this phase of the program, 12 by NASA, 4 by MERADCOM, and 1 by the Canadian government.

The assistance and cooperation of Robert Dare from Battronic Truck Corp., the vehicle manufacturer, are greatly appreciated. The Energy Research and Development Administration provided funding support and guidance during this project.

U.S. customary units were used in the collection and reduction of data. The units were converted to the International System of Units for presentation in this report. U.S. customary units are presented in parentheses. The parameters, symbols, units, and unit abbreviations used in this report are listed here for the convenience of the reader.

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Parameter	Symbol	SI units		U.S. customary units	
		Unit	Abbreviation	Unit	Abbreviation
Acceleration	a	meter per second squared	m/s^2	mile per hour per second	mph/s
Area	---	square meter	m^2	square foot; square inch	ft^2, in^2
Energy	---	megajoule	MJ	kilowatt hour	kWh
Energy consumption	E	megajoule per kilometer	MJ/km	kilowatt hour per mile	kWh/mile
Energy economy	---	megajoule per kilometer	MJ/km	kilowatt hour per mile	kWh/mile
Force	P	newton	N	pound force	lbf
Integrated current	---	ampere hour	Ah	ampere hour	Ah
Length	---	meter	m	inch, foot, mile	in., ft, ---
Mass, weight	W	kilogram	kg	pound mass	lbm
Power	P	kilowatt	kW	horsepower	hp
Pressure	---	kilopascal	kPa	pound per square inch	psi
Range	---	kilometer	km	mile	---
Specific energy	---	megajoule per kilogram	MJ/kg	watt hour per pound	Wh/lbm
Specific power	---	kilowatt per kilogram	kW/kg	kilowatt per pound	kW/lbm
Speed	V	kilometer per hour	km/h	mile per hour	mph
Volume	---	cubic meter	m^3	cubic inch, cubic foot	in^3, ft^3

OBJECTIVES

The objectives of the tests were to measure vehicle maximum speed, range at constant speed, range over stop-and-go driving schedules, maximum acceleration, gradeability, gradeability limit, road energy consumption, road power, indicated energy consumption, braking capability, and battery charger efficiency for the Battronic Minivan electric delivery van.

TEST VEHICLE DESCRIPTION

The Battronic Minivan is a battery-powered electric truck with a curb weight of approximately 2600 kilograms (5730 lbm) and a payload capability of 363 kilograms (800 lbm). It is a two-passenger van with a sliding cab door on each side (fig. 1). Each cab door has a sliding sash window. The vehicle has a large single rear door, which provides easy access to the rear compartment (fig. 2). A complete description of the vehicle is given in reference 3. More-detailed characteristics of the vehicle are presented in appendix A and below.

The vehicle is powered by a 31.3-kilowatt (42-hp), series-wound, direct-current (DC) traction motor with thermal protection. The controller, located in the front of the vehicle (fig. 3), is a General Electric reactance, solid-state, SCR, DC chopper with bypass contactors. It has fused protection for the control circuits. Field weakening and automatic current limiting are also provided by the controller.

The battery of the Battronic Minivan is a semi-industrial, lead-acid battery. It is rated at 112 volts and is assembled into two modules, one located on each side of the rear compartment. Figure 4 depicts the battery module located on the passenger side of the vehicle. The two modules are connected electrically in series when installed in the vehicle. An on-board battery charger is provided to charge these modules. It may be connected to either 115 or 230 volts alternating current (AC) and is equipped with an automatic timer.

An accessory 12-volt battery is furnished to power the lights, horn, radio, etc. This battery is charged continuously from the main batteries through a DC-to-DC converter.

Driveline gear ratio is controlled by a transfer-case shift lever. The transfer case has two ratios and can be shifted only when the vehicle is standing still. The high gear position is used for highway driving; the low gear position is used for normal city driving and hill climbing. A neutral position is provided to disengage the motor and gearbox.

A directional control lever is used to control the direction of current flow to the field of the motor. This allows the vehicle to move forward or in reverse. With this lever in the neutral position, no current can flow to the field circuit and operation of the vehicle is prevented.

To place the vehicle in motion requires releasing the hand brake, moving the shift lever to the proper gear, placing the directional control lever in forward or reverse, and depressing the accelerator pedal. Removing pressure from the accelerator pedal shuts off all power to the motor. The brakes are conventional hydraulic drum brakes. No regenerative braking is provided.

INSTRUMENTATION

The Battronic Minivan was instrumented to measure vehicle speed and range, battery voltage and current, motor voltage and current, temperatures of the motor frame and battery case, and battery charger power. Most of these measurements were telemetered to a central instrumentation facility, where they were recorded on magnetic tape. The telemetry system is described in appendix B.

A schematic diagram of the electric propulsion system with the instrumentation sensors is shown in figure 5. A Nucleus Corporation Model NC-7 precision speedometer (fifth wheel) was used to measure vehicle speed and distance traveled. Auxiliary equipment used with the fifth wheel included a Model ERP-X1 electronic pulser for distance measurement, a Model NC-PTE pulse totalizer, a Model ESS/E expanded-scale speedometer, and a programmable digital attenuator. The fifth wheel was calibrated before each test by rotating it on a constant-speed fifth-wheel calibrator drum mounted on the shaft of a synchronous AC motor. The accuracy of the distance and velocity readings was within ±0.5 percent of the readings. Distance and velocity were recorded on magnetic tape through the telemetry system.

The integrated battery current was measured for the battery pack with a current shunt and an on-board current integrator. It was recorded manually after each test. This measurement provides the ampere-hours delivered by the battery pack. The current integrator is a Model SHR-C3 Curtis current integrator and was calibrated periodically to within ±1 percent of reading.

Motor current, motor voltage, and motor temperature were measured to determine motor performance. A 1000-ampere current shunt was used in an attempt to measure motor current. Excessive noise in the motor current signal made the measurement useless. One thermocouple was placed on each battery module to monitor battery temperature. These measurements were telemetered and recorded on magnetic tape. Battery electrolyte temperatures and specific gravities were measured manually before and after the tests.

Power for the fifth wheel and current integrator was provided from an automotive 12-volt starting, lighting, and ignition (SLI) battery. A Tripp Lite 500-watt DC/AC inverter provided the AC power. The power for the telemetry system was obtained from the battery power pack described in appendix B.

All instruments were calibrated periodically. The integrators and strip-chart recorders were calibrated with a Hewlett-Packard Model 6920 B meter calibrator, which has an accuracy of 0.2 percent of reading and a usable range of 0.01 to 1000 volts.

The current and voltage into the battery and the energy into the battery charger were measured while the battery was being recharged after each test. The current and voltage to the battery were recorded on a Honeywell 195 Electronik two-channel strip-chart recorder. The current measurement used a 500-ampere current shunt in all the test series except one. In that series a laboratory wattmeter with Hall-effect current sensors manufactured by Ohio Semitronics, Inc., was used to measure charger efficiency. The energy delivered to the charger was measured with a General Electric 1-50A single-phase residential kilowatt-hour meter.

TEST PROCEDURES

The tests described in this report were performed at the Dynamic Science Test Track, a two-lane, 3.22-kilometer (2-mile) asphalt track located in Phoenix, Arizona. A complete description of the track is given in appendix C. When the vehicle was delivered to the test track, the pretest checks described in appendix D were conducted. The first test was a formal shakedown to familiarize the driver with the operating characteristics of the vehicle, to check out all instrumentation systems, and to determine the vehicle's maximum speed (appendix D). All tests were run in accordance with ERDA Electric and Hybrid Vehicle Test And Evaluation Procedure ERDA-EHV-TEP (appendix E of ref. 1) at the gross weight of the vehicle, 2860 kilograms (6300 lbm).

Range Tests at Constant Speed

The vehicle speed for the highest constant-speed range test was determined during checkout tests of the vehicle. It was specified as 95 percent of the minimum speed the vehicle could maintain on the test track when it was traveling at full power. This speed was 84 kilometers per hour (52 mph) in high gear and 59.5 kilometers per hour (37 mph) in low gear for the Battronic Minivan.

Range tests at constant speeds were run for the Battronic Minivan in both low and high gear. The test speeds were 40 and 60 kilometers per hour (25 and 37 mph) in low gear, and 72 and 84 kilometers per hour (45 and 52 mph) in high gear. The speed was held constant within ± 1.6 kilometers per hour (1 mph), and the test was terminated when the vehicle could no longer maintain 95 percent of the test speed. The range tests were run at least twice at each speed.

Range Tests under Driving Schedules

Both the 32-kilometer-per-hour (20-mph) schedule B and the 48-kilometer-per-hour (30-mph) schedule C stop-and-go driving cycles, shown in figure 6, were run with this vehicle. A complete description of the cycle tests is given in appendix E of reference 1. A special instrument, called a cycle timer, was developed at the Lewis Research Center to assist in accurately running these tests. Details of the cycle timer are given in appendix D. The cycle tests were terminated when the test speed could not be attained in the time required under maximum acceleration.

Acceleration and Coast-Down Tests

The maximum acceleration of the vehicle was measured on a level road with the battery fully charged and 40 and 80 percent discharged. Four runs, two in each direction, were conducted at each of these three states of charge with the vehicle in high gear. In low gear the tests were conducted with the battery 40 and 80 percent discharged. Depth of discharge was determined from the number of ampere-hours removed from the batteries. Acceleration runs were made on the southern straight section of the track and coast-downs on the northern straight section (appendix C, fig. C-1). Coast-down data were taken after the acceleration test with the transmission in neutral and with fully charged batteries in order to start the coast-down run from the maximum attainable vehicle speed.

Braking Tests

Braking tests on the vehicle were conducted

(1) To determine the minimum stopping distance in a straight-line emergency stop

(2) To determine the controllability of the vehicle while braking in a turn on both wet and dry pavement

(3) To determine the brake recovery after the vehicle was driven through 0.15 meter (6 in.) of water at 8 kilometers per hour (5 mph) for 2 minutes

(4) To determine the parking brake effectiveness on an incline

Instrumentation used during the braking test included a fifth wheel programmed to determine stopping distance, a brake pedal force transducer, and a decelerometer. A complete description of the braking tests is given in the discussion of test results and in appendix E of reference 1.

Tractive Force Tests

The maximum grade-climbing capability of the test vehicle can be determined from tractive force tests by towing a second vehicle. The driver of the towed vehicle, by applying the footbrake, maintains a speed of about 3 kilometers per hour (2 mph) while the test vehicle is being driven with a wide-open throttle. The force is measured by a 13 000-newton (3000-lbf) load cell attached to the tow chain between the vehicles. The tests are normally run with the batteries fully charged and 40 and 80 percent discharged. However, a problem arose each time an attempt was made to tow the second vehicle with the Battronic Minivan. The motor drew such a large amount of current to get the vehicles moving that the 400-ampere fuse in the main battery circuit kept blowing out. Therefore, these tests could not be completed. The initial thrust of the vehicle prior to opening of the fuse was calculated to be equivalent to a gradeability limit in excess of 50 percent.

Charger Efficiency Tests

Two methods were used to determine charger efficiency as a function of charge time. In the first method a residential kilowatt-hour meter was used to measure input power to the charger by counting rotations of the disk and applying the meter manufacturer's calibration factor. The charger output power was determined by multiplying the average value of current by the average value of voltage. Residential kilowatt-hour meters are calibrated for sinusoidal waves only. The error in measuring input power depends on the wave shape and may be as high as 5 percent. The method of determining output power is correct only when either the voltage or the current is a constant during each charging pulse. The battery voltage does change during each charging pulse, which introduces a small error. The current shunts used to measure current are inaccurate for pulsing current. The error depends on frequency and wave shape and may exceed 10 percent.

In the other method used for determining charger efficiency a 50-kilowatt power meter was used on both the input and output of the charger and a Hall-effect current probe was used for current measurements. To minimize errors, the same meter and current probe were used for both the input measurement and the output measurement. The average power measured was about 4 percent of full scale. The influence of these inaccuracies on the determination of charger efficiency is discussed in the component section of this report.

TEST RESULTS

Range

The data collected from all the range tests are summarized in table I. Shown in the table are the test date, the type of test, the environmental conditions, the range test results, the ampere-hours into and out of the battery, and the energy into the charger. These data were used to determine vehicle range, battery efficiency, and energy consumption.

During most of the test period, the winds were variable and gusty. Even though the wind was less than 16 kilometers per hour (10 mph), on several occasions it was blowing in different directions and at different velocities at two positions on the track. There was no indication that this variation in wind velocity significantly affected the range or other test results as long as the measured winds were less than about 16 kilometers per hour.

The maximum speed of the vehicle was measured during the checkout tests. It is defined as the average speed that could be maintained on the track under full power. The measured maximum speed was 90 kilometers per hour (56 mph) for this vehicle. This differs from the maximum speed used in the range tests.

Two 40-kilometer-per-hour (25-mph), three 60-kilometer-per-hour (37-mph), two schedule B, and two schedule C tests were run in low gear on the Battronic Minivan. In high gear, three 72-kilometer-per-hour (45-mph) and two 84-kilometer-per-hour (52-mph) constant-speed range tests were run. The constant-speed test results are plotted in figure 7. Some tests in table I were not included in the data averaging because winds exceeding the specifications occurred during these tests.

Maximum Acceleration

The maximum acceleration of the vehicle was determined with the batteries fully charged and 40 and 80 percent discharged. Since the transmission had both a high gear and a low gear in the forward direction, the acceleration tests were run in both gears. The results of these tests are shown in figure 8(a) for the tests run in high gear and in figure 8(b) for low gear. These data are tabulated in table II. The average acceleration $\bar{a}_n$ was calculated for the time period t_{n-1} to t_n, where the vehicle speed increased from V_{n-1} to V_n, from the equation

$$\bar{a}_n = \frac{V_n - V_{n-1}}{t_n - t_{n-1}}$$

and the average speed of the vehicle $\bar{V}$ from the equation

$$\bar{V} = \frac{V_n + V_{n-1}}{2}$$

Maximum acceleration as a function of speed is shown in figure 9 and table III.

Gradeability

The maximum specific grade, in percent, that a vehicle can climb at an average vehicle speed $\bar{V}$ was determined from maximum acceleration tests by using the equations

$$G = 100 \tan (\sin^{-1} 0.1026\, \bar{a}_n) \quad \text{for } V \text{ in km/h}$$

in SI units

or

$$G = 100 \tan (\sin^{-1} 0.0455\, \bar{a}_n) \quad \text{for } \bar{V} \text{ in mph}$$

in U.S. customary units

where $\bar{a}_n$ is average acceleration in meters per second squared (mph/sec). The maximum grade the Minivan can negotiate as a function of speed is shown for both gears in figure 10 and table IV.

Gradeability Limit

Gradeability limit is defined by the SAE J227a procedure as the maximum grade on which the vehicle can just move forward. The limit can be determined by measuring the tractive force with a load cell while towing a second vehicle at about 3 kilometers per hour (2 mph). It can be calculated from the equations

$$\text{Gradeability limit in percent} = 100 \tan\left(\sin^{-1} \frac{P}{9.8\ W}\right)$$

in SI units

or

$$\text{Gradeability limit in percent} = 100 \tan\left(\sin^{-1} \frac{P}{W}\right)$$

in U.S. customary units

where

P tractive force, N (lbf)

W gross vehicle weight, kg (lbm)

The tractive force that the Battronic Minivan was capable of exerting for the required speed and time (appendix E of ref. 1) was not attained because the current drawn from the battery was so large that it kept blowing out the main battery fuse. However, the initial thrust of the vehicle recorded a tractive force of nearly full scale (13 000 N (3000 lbf)) before the fuse blew. The resultant gradeability should thus be in excess of 50 percent. Since this is only the initial force exerted for very short duration, the gradeability may decrease over a longer period of time. Results given in reference 4 indicate a maximum gradeability capability of over 31 percent when the vehicle was driven for 18 meters (60 ft) at a speed of 8 kilometers per hour (5 mph).

Road Energy Consumption

Road energy is a measure of the energy consumed per unit distance in overcoming the vehicle's aerodynamic and rolling resistance plus the energy consumed in the differential drive shaft and the portion of the transmission rotating when in neutral. It was obtained during coast-down tests, when the differential was being driven by the wheels, and thus may be different than the energy consumed when the differential is being driven by the motor.

The Battronic Minivan was driven to nearly its maximum speed, the accelerator pedal was released, and the transfer-case shift lever was quickly moved to the neutral position. This procedure disconnected the drive motor and allowed the vehicle to coast freely to zero speed.

Road energy consumption E_n was calculated from the following equations:

$$E_n = 2.78 \times 10^{-4} W \frac{V_{n-1} - V_n}{t_n - t_{n-1}}, \text{ MJ/km}$$

or

$$E_n = 9.07 \times 10^{-5} W \frac{V_{n-1} - V_n}{t_n - t_{n-1}}, \text{ kWh/mile}$$

where

W vehicle mass, kg (lbm)

V vehicle speed, km/h (mph)

t time, s

The results of the road energy calculations are shown in figure 11 and table V.

Road Power Requirements

The calculation of road power is analogous to the road energy calculation. It is a measure of the power needed to overcome vehicle aerodynamic and rolling resistance plus the power losses from the differential, the drive shaft, and a portion of the transmission. The road power P_n required to propel a vehicle at various speeds is also determined from the coast-down tests. The following equations are used:

$$P_n = 3.86 \times 10^{-5} W \frac{V_{n-1}^2 - V_n^2}{t_n - t_{n-1}}, \text{ kW}$$

or

$$P_n = 6.08\times10^{-5} W \frac{V_{n-1}^2 - V_n^2}{t_n - t_{n-1}}, \text{ hp}$$

The results of road power calculations are shown in figure 12 and table VI.

Indicated Energy Consumption

The vehicle indicated energy consumption is defined as the energy required to recharge the battery after a test divided by the vehicle range achieved during the test, where the energy is the input to the battery charger.

The energy input to the battery charger was measured with a residential kilowatt-hour meter after each range test. Some overcharge of the batteries was usually required in order to assure that all battery cells were fully charged and that the pack was equalized. The reported energy usage may be higher than would be experienced with normal vehicle field operation. Indicated energy consumption as a function of vehicle speed is presented in figure 13 and table VII for the constant-speed tests.

Braking Capability

Simplified braking capability tests were conducted according to the procedure outlined in appendix E of reference 1 in order to provide a preliminary evaluation of the vehicle's braking capabilities. The procedure also includes tests for handling, but at ERDA's direction they were not conducted on this vehicle.

Straight-line stops. - Six straight-line stops from 48 kilometers per hour (30 mph) were made, three from each direction. Stopping distance varied from 16 meters (53 ft) to 18 meters (60 ft). Then six straight-line stops from the maximum speed of 83 kilometers per hour (52 mph) were made, three from each direction. Stopping distance varied from 60 meters (198 ft) to 67 meters (220 ft).

Stops on a curve. - Three stops were made going into a 0.3-g curve from 84 kilometers per hour (52 mph) on dry pavement turning right, and three stops were made on the same curve turning left. No difficulties were encountered in stopping within the 3.6-meter (12-ft) lane. The stopping distances were consistently about 72 meters (235 ft). The tests were repeated in a 0.2-g turn on wet pavement. Again the vehicle stopped smoothly with no problems. The stopping distances averaged slightly higher for these tests, approximately 74 meters (244 ft).

Wet brake recovery. - Three baseline stops were made from 48 kilometers per hour (30 mph) with dry brakes, decelerating at 3 meters per second squared (10 ft/sec^2). The average pedal force was 294 newtons (66 lbf). After the vehicle was driven through 0.15 meter (6 in.) of water at 8 kilometers per hour (5 mpn) for 2 minutes, the tests were repeated. The first stop was made with a pedal force of 330 newtons (74 lbf). The brakes had fully recovered on the fifth stop.

Parking brake. - Tests were conducted to determine parking brake effectiveness. The vehicle did not pass the parking brake test the first time. The brakes were adjusted and the tests were repeated. After adjustment, the braking force required to hold the vehicle on a 30-percent slope was 446 newtons (100 lbf) facing uphill and 350 newtons (79 lbf) facing downhill, with the force being applied 3.8 centimeters (1.5 in.) from the top of the brake handle. No slippage during the 5-minute hold was observed with the parking brake set as described. The test was run twice in each attitude. Since the test specification calls for a maximum allowable force on the lever of 400 newtons (90 lb) the vehicle successfully passed the minimum requirements in the nose downward position but failed in the upslope attitude even after the brake adjustment was made.

COMPONENT PERFORMANCE AND EFFICIENCY

Battery Charger

The battery charger employs a ferroresonant transformer with a center-tapped secondary. The center-tapped secondary is connected through diodes for full-wave rectification.

The battery charger efficiency test results are presented in figure 14. The indicated efficiencies of the charger, as calculated from the readings on the residential kilowatt-hour meter and the average values of charger output voltages and amperes, vary from 7 percent less to 5 percent more than the efficiencies that were calculated from wattmeter readings. Which set of values is more nearly correct has not been determined. Since the power efficiency is fairly constant over the entire time period, the energy efficiency is approximately equal to the average of the power efficiencies.

The total amount of energy that is delivered to the battery depends not only on the charger efficiency, but also on the system used to terminate the charge. The Battronic charger uses a timer set by the operator to terminate the charge. Since variations in the battery voltage-current relationship (due to temperature, age, etc.) can drastically affect the charging current, the time required to attain full charge also varies. Consequently, the amount of energy that is delivered to the battery is largely determined by the judgment of the operator. During the track tests the battery was always purposely overcharged to assure full capacity for all cells.

Battery

The battery used to power the Battronic Minivan for this test was a two-module General Battery Corp. semi-industrial battery. Each module contained twenty-eight EV-330 cells. The battery capacity, as rated by the manufacturer, is 330 ampere-hours at a discharge current of 55 amperes (6-h rate) to a voltage cutoff of 1.70 volts per cell (47.6 V/module). The cell characteristics as supplied by the battery manufacturer are shown in table VIII.

Battery acceptance. - Before road testing was started, the batteries supplied by the vehicle manufacturer were normally tested for battery capacity and terminal integrity as specified in appendix D. Both tests were modified for the Battronic Minivan.

Prior to delivery of the battery a 92.4-ampere (3-h rate) battery discharge test was conducted by the battery supplier at his facility. This test was used in place of the battery capacity test normally conducted before vehicle tests. The results of the test are shown in figure 15. The measured average capacity of the battery at 92.4 amperes was 285 ampere-hours to a 47.6-volt-per-module cutoff voltage. As the manufacturer rated the battery at 277 ampere-hours at the 92.4-ampere rate, the battery passed the test.

The cells in each battery module are permenantly connected together with lead connectors. As these connectors cannot be easily loosened, there was no need to conduct the 300-ampere terminal integrity test. The connectors were inspected carefully, and since there were no visible defects the battery was accepted.

Controller

The Battronic Minivan controller was manufactured by the General Electric Co. The controller consists of an SCR chopper, bypass contactors, and field weakening contactors. Up to about 80 percent of the maximum vehicle speed, the speed is controlled by applying a series of voltage pulses to the motor. As the accelerator pedal is depressed, both the pulse width and the repetition rates are increased to increase the percentage of time that the pulses are applied to the motor. Increasing the percent of time increases the average voltage applied to the motor and consequently its speed.

At about 80 percent of the maximum vehicle speed the average value of motor voltage approaches the battery voltage. Any difference results from controller losses, primarily due to the voltage drop across the SCR. Closing the bypass contactor eliminates the controller voltage drop, increasing the motor voltage and vehicle speed. If additional speed is desired, the field weakening contactor is closed, diverting some of the series field current through a resistor. This increases the motor speed.

Information regarding the efficiency of the controller in the chopper mode is not available. Once the controller is bypassed, the only losses result from the contactor coil resistance and the small voltage drop across the contacts. Consequently, the controller efficiency approaches 100 percent. In the field weakening mode, additional losses appear in the resistor. These losses reduce the controller efficiency.

Motor

The Battronic Minivan motor is a conventional DC series-wound traction motor. The motor was manufactured by the General Electric Co. The 0.4-hour rating of the motor was 31.5 kilowatts (42 hp) at 2300 rpm, 390 amperes, and 94 volts. The motor has Class F insulation and an internal cooling fan.

VEHICLE RELIABILITY

The Minivan was quite reliable during the test period, with only three minor problems. During a maximum-speed range test at 84 kilometers per hour (52 mph), a 300-ampere motor protection fuse blew after approximately 8 minutes. The vehicle manufacturer recommended replacing the fuse with a 400-ampere fuse. No further problems were encountered with the higher rating fuse. During the test period the charger timer failed. The charger was operated without a timer for the rest of the test period. The 12-volt charger also failed and had to be replaced early in the test program.

APPENDIX A

VEHICLE SUMMARY DATA SHEET

1.0 Vehicle manufacturer: Battronic Truck Corp.
Boyertown, Pa.

2.0 Vehicle: Battronic Minivan

3.0 Price and availability: $15,000; production upon request

4.0 Vehicle weight and load

- 4.1 Curb weight, kg (lbm): 2690 (5930)
- 4.2 Gross vehicle weight, kg (lbm): 2858 (6300)
- 4.3 Cargo weight, kg (lbm): 227 (500)
- 4.4 Number of passengers: 2
- 4.5 Payload, kg (lbm): 363 (800) including driver

5.0 Vehicle size

- 5.1 Wheelbase, m (in.): 2.40 (94.5)
- 5.2 Length, m (in.): 3.69 (145)
- 5.3 Width, m (in.): 1.98 (77.9)
- 5.4 Height, m (in.): 2.27 (89)
- 5.5 Head room, m (in.): 1.10 (43.5)
- 5.6 Leg room, m (in.): 0.37 (14.5)
- 5.7 Frontal area, m^2 (ft^2): 3.9 (42)
- 5.8 Road clearance, cm (in.): 33 (13)
- 5.9 Number of seats: 2

6.0 Auxiliaries and options

- 6.1 Lights (number, type, and function): 2 headlamp; 2 park; 2 brake; 1 backup; 2 sidelights at rear; 2 sidelights and directional front and rear

6.2 Windshield wipers yes

6.3 Windshield washers yes

6.4 Defroster yes

6.5 Heater yes (Hunter UH-47-6; gasoline, 7.57 liter (2 gal))

6.6 Radio yes (Motorola, AM, TM-292 M)

6.7 Fuel gage yes (Curtis 11611)

6.8 Amperemeter armature and 12-volt auxiliary battery

6.9 Tachometer no

6.10 Speedometer yes

6.11 Odometer yes (and trip mileage indicator)

6.12 Right- or left-hand drive left

6.13 Transmission 2 speed; 1:1 and 1:1.96 ratios

6.14 Regenerative braking no

6.15 Mirrors left and right outside; interior

6.16 Power steering no

6.17 Power brakes no

6.18 Other

7.0 Battery

7.1 Propulsion battery

7.1.1 Type and manufacturer General Battery Corp. Type 56-EV-330

7.1.2 Number of modules 2

7.1.3 Number of cells 56 (28 per module)

7.1.4 Operating voltage, V 112

7.1.5 Capacity, Ah 330 (at a 6-h discharge rate)

7.1.6 Size of each module, m (in.) height, 0.58 (23); width, 0.50 (19.5); length, 0.96 (37.75)

7.1.7 Weight, kg (lbm) 1043 (2300)

7.1.8 History (age, number of cycles, etc.)

7.2 Auxiliary battery

7.2.1 Type and manufacturer Titan Series 6000 Group 27; General Battery Corp.

7.2.2 Number of cells 6

7.2.3 Operating voltage, V 12

7.2.4 Capacity, Ah 36

7.2.5 Size, m (in.) height, 0.20 (8); width, 0.17 (6.5); length, 0.30 (12)

7.2.6 Weight, kg (lbm)

8.0 Controller

8.1 Type and manufacturer 510 R; SCR; General Electric

8.2 Voltage rating, V 112

8.3 Current rating, A 500

8.4 Size, m (in.) components on a mounting plate: width, 0.47 (18.5); length, 1.07 (42)

8.5 Weight, kg (lbm)

9.0 Propulsion motor

9.1 Type and manufacturer DC traction series; General Electric, 5 BT 2376C6

9.2 Insulation class F (115° C)

9.3 Voltage rating, V 94

9.4 Current rating, A

9.5 Horsepower (rated), kW (hp) 31.5 (42) (0.4-h duty)

9.6 Size, m (in.) diameter, 0.33 (13); length, 0.61 (24)

9.7 Weight, kg (lbm)

9.8 Speed (rated), rpm 2300

10.0 Battery charger

10.1 Type and manufacturer EV 112 A/C 30; C&D Batteries, Division of Eltra Corp.

10.2 On- or off-board type on-board

10.3 Input voltage required, V 120/208/240

10.4 Peak current demand, A 30/15

10.5 Recharge time, h

10.6 Size, m (in.) height, 0.55 (21.5); width, 0.25 (10); length, 0.56 (22)

10.7 Weight, kg (lbm)

10.8 Automatic turnoff feature yes

11.0 Body

11.1 Manufacturer and type Battronic van

11.2 Materials steel

11.3 Number of doors and type 3; left and right sliding; rear, hinged

11.4 Number of windows and type 2 pane windshield; 1 pane each front quarter; 2 pane sliding each side door; 1 pane each rear quarter; 1 pane rear door

11.5 Number of seats and type 2 bucket, front

11.6 Cargo space volume, m^3 (ft^3) 4.76 (168)

11.7 Cargo space dimensions, m (ft) height, 1.63 (64); width, 1.83 (72); length, 1.83 (72), minus wheel well

12.0 Chassis

12.1 Frame

12.1.1 Type and manufacturer Battronic Truck Corp.; box

12.1.2 Materials steel

12.1.3 Modifications

12.2 Springs and shocks

12.2.1 Type and manufacturer springs - 6 leaf laminated; shocks - direct-acting hydraulic cylinders

12.2.2 Modifications none

12.3 Axles

12.3.1 Manufacturer Spicer (Dana)

12.3.2 Front Clark

12.3.3 Rear semi-floating, hypoid gears, flanged axle shafts

12.4 Transmission

12.4.1 Type and manufacturer

12.4.2 Gear ratios rear axle, 3.07; transfer box, 1:1 and 1:1.96

12.4.3 Driveline ratio 6.02:1 and 3.07:1

12.5 Steering

12.5.1 Type and manufacturer worm and nut (recirculating ball); Saginaw

12.5.2 Turning ratio 24:1

12.5.3 Turning diameter, m (ft) 11.3 (37)

12 6 Brakes

12.6.1 Front hydraulic drum

12.6.2 Rear hydraulic drum

12 6.3 Parking mechanical on rear axle; two-position cable

12.6.4 Regenerative no

12 7 Tires

12.7 1 Manufacturer and type Firestone; Transport 110, 6-ply rating, load range C

12 7.2 Size 6.70-15

12.7.3 Pressure, kPa (psi):

Front 310 (45)

Rear 310 (45)

12.7.4 Rolling radius, m (in.) 0.33 (12.9)

12.7.5 Wheel weight, kg (lbm):

Without drum _____

With drum 23 (50.7)

12.7.6 Wheel track, m (in.):

Front _____

Rear _____

13.0 Performance

13.1 Manufacturer-specified maximum speed (wide-open throttle), km/h (mph)

_____

13.2 Manufacturer-recommended maximum cruise speed (wide-open throttle), km/h (mph) _____

13.3 Tested at cruise speed, km/h (mph) 72.4 (45); 83.7 (52)

APPENDIX B

DATA ACQUISITION

Data acquired from the test vehicle are conditioned onboard the vehicle and transmitted to the Data Acquisition Center where they are demodulated and recorded on magnetic tape (fig. B-1).

The following paragraphs provide a detailed description of system components. Instrumentation calibration procedures and test procedures relative to the data acquisition system are also described.

Signal Conditioning Equipment

The signal conditioning equipment has a modular or building-block configuration. The basic building block is the remote signal conditioning module (RSCM), which consists of all the necessary functions required to take the basic transducer information and store it on magnetic tape. Each RSCM handles 14 data channels.

Internally, the RSCM consists of all the necessary components required to signal condition, modulate onto Inter-Range Instrumentation Group (IRIG) constant-bandwidth frequency-modulated (FM) channels, and transmit a transducer output signal to a remote tape recorder. Figure B-2 is the system diagram defining this RSCM.

The signal conditioning amplifiers in the front end of the RSCM provide suitable gain and balance to normalize all transducer outputs into common formats and to drive the voltage-controlled oscillators (VCO's). Each amplifier has a built-in, isolated bridge power supply regulated at 5.0 volts DC that negates loading effects from other transducers and changes in output due to supply battery variations. This power supply is used either alone, divided down by 0.1-percent metal film resistors, or in series with other supplies to provide a highly accurate and stable voltage insertion calibration of the entire system, channel by channel.

The VCO's convert analog voltages to a frequency-modulated unbalanced signal. The center frequencies of the VCO's are set at values defined by IRIG 106-71 for constant-bandwidth channels (table B-1). The $\pm$2.5-volt outputs from the amplifier provide $\pm$100-percent deviation of the VCO's. Using a mix of A and B channels provides an optimum combination of data frequency response, resolution, percentage of deviation, and channel density in each multiplex.

The system is designed to provide 1000-hertz data channel bandwidth on all A channels and 2000-hertz channel bandwidth on all B channels. The 14 VCO outputs are mixed onto a common bus which provides the output signal to be recorded. An external 28-volt battery is used to power the RSCM.

Each RSCM weighs under 9 kilograms (20 lbm) and covers approximately 390 square centimeters (60 in^2) of floor space. All input and output connections and final adjustments are accessible from the top of the module.

System Accuracy

Table B-2 represents the system errors for the data acquisition system. The values are taken from the component specifications. As there are several information conversions through the system, there was an attempt to translate the specifications into a "common error domain." Each device in the system has a set of parameters that represent its performance in a particular region of the multidimensional space (e.g., an accelerometer converts an acceleration into a voltage (actually an energy conversion) with some nonlinearity of information conversion). There is a conversion from analog voltage to frequency with a corresponding nonlinearity in the VCO. The tape recorder has to handle the information mechanically with high accuracy because a change in tape speed represents a change in frequency which, in turn, represents a change in the original analog voltage.

Tape Recorders

The tape recorder has 14 IRIG-compatible channels, with the recording channels individually controlled so that multiple recording passes may be made on the same tape. Capstan speed accuracy of 0.01 percent is obtained by use of a tape speed compensator system while flutter is held to 0.22 percent. Time base and dynamic skew are 0.5 and 25 microseconds, respectively.

APPENDIX C

DESCRIPTION OF VEHICLE TEST TRACK

The test track used to conduct the tests described in this report is located in Phoenix, Arizona. The track is owned and operated by Dynamic Science, a subsidiary of Talley Industries.

The test track is a paved, continuous two-lane, 3.2-kilometer- (2-mile-) long oval with an adjacent 40 000-square-meter (10-acre) skid pad. The inner lane of the track is not banked and was used for all cycle tests and all constant-speed tests of 56 kilometers per hour (35 mph) or under. The outer lane has zero lateral acceleration at 80 kilometers per hour (50 mph) and was used for tests over 56 kilometers per hour (35 mph). An elevation survey of the track is shown in figure C-1. Average grade is 0.66 percent on the northern straight section and 0.76 percent on the southern straight section. The surface of the track and skid pad is asphaltic concrete with a dry locked-wheel skid number of 82 and a wet locked-wheel skid number of 71.

Wet and dry braking-in-turn tests were conducted on the skid pad. Wet recovery tests were conducted on the test track after driving through the wet-brake water trough located near the northern straight section of the track. Both 20- and 30-percent grades are available for parking brake tests.

APPENDIX D

VEHICLE PREPARATION AND TEST PROCEDURE

Vehicle Preparation

When a vehicle was received at the test track, a number of checks were made to assure that it was ready for performance tests. These checks were recorded on a vehicle preparation check sheet, such as the one shown in figure D-1. The vehicle was examined for physical damage when it was removed from the transport truck and before it was accepted from the shipper. Before the vehicle was operated, a complete visual check was made of the entire vehicle including wiring, batteries, motor, and controller. The vehicle was weighed and compared with the manufacturer's specified curb weight. The gross vehicle weight (GVW) was determined from the vehicle sticker GVW. If the manufacturer did not recommend a GVW, it was determined by adding 68 kilograms (150 lbm) per passenger plus any payload weight to the vehicle curb weight.

The wheel alignment was checked, compared, and corrected to the manufacturer's recommended alignment values. The battery was charged and specific gravities taken to determine if the batteries were equalized. If not, an equalizing charge was applied to the batteries. The integrity of the internal interconnections and the battery terminals was checked by drawing either 300 amperes or the vehicle manufacturer's maximum allowed current load from the battery through a load bank for 5 minutes. If the temperature of the battery terminals or interconnections rose more than 60 degrees Celsius above ambient, the test was terminated and the terminal was cleaned or the battery replaced. The batteries were then recharged and a battery capacity check was made. The battery was discharged in accordance with the battery manufacturer's recommendations. To pass this test, the capacity must be within 20 percent of the manufacturer's published capacity at the published rate.

The vehicle manufacturer was contacted for his recommendations concerning the maximum speed of the vehicle, tire pressures, and procedures for driving the vehicle. The vehicle was photographed head-on with a 270-millimeter telephoto lens from a distance of about 30.5 meters (100 ft) in order to determine the frontal area.

Test Procedure

Each day, before a test, a test checklist was used. Two samples of these checklists are shown in figure D-2.

The first item under driver instructions on the test checklist is to complete the pretest checklist (fig. D-3).

Data taken before, during, and after each test were entered on the vehicle data sheet (fig. D-4). These data include

(1) Average specific gravity of the battery

(2) Tire pressures

(3) Fifth-wheel tire pressure

(4) Test weight of the vehicle

(5) Weather information

(6) Battery temperatures

(7) Time the test was started

(8) Time the test was stopped

(9) Ampere-hours out of the battery

(10) Fifth-wheel distance count

(11) Odometer readings before and after the tests

The battery charge data taken during the charge cycle were also recorded on this data sheet. These data include the average specific gravity of the battery after the test, the kilowatt-hours and ampere-hours put into the battery during the charge, and the total time of the charge.

To prepare for a test, the specific gravities were first measured for each cell and recorded. The tire pressures were measured and the vehicle was weighed. The weight was brought up to the GVW by adding sandbags. The instrumentation was connected, and power from the instrumentation battery was applied. All instruments were turned on and warmed up. The vehicle was towed to the starting point on the track. If the data were being telemetered, precalibrations were applied to both the magnetic tape and the oscillograph. The fifth-wheel distance counter and ampere-hour integrator counter were reset to zero, and thermocouple reference junctions were turned on. The test was started and was carried out in accordance with the test checklist. When the test was terminated, the vehicle was brought to a stop and the post-test checks were made in accordance with the post-test checklist (fig. D-5). The driver recorded on the vehicle data sheet the time, the odometer reading, the ampere hour integrator reading, and the fifth-wheel distance reading. The post-calibration steps were then applied to the magnetic tape and the oscillograph. At the end of the test, weather data were recorded on the vehicle data sheet. All instrumentation power was turned off, the instrumentation battery was disconnected, and the fifth wheel was raised. The vehicle was then towed back to the garage, the post-test specific gravities were measured for all cells and the vehicle was placed on charge.

After the test, the engineer conducting the test completed a test summary sheet (fig. D-6). This data sheet provides a brief summary of the pertinent information received from the test. Another data sheet, the engineer's data sheet (fig. D-7), was also filled out. This data sheet summarizes the engineer's evaluation of the test and provides a record of problems, malfunctions, changes to instrumentation, etc., that occurred during the test.

Weather data. - Wind velocity and direction and ambient temperature were measured at the beginning and at the end of each test and every hour during the test. The wind anemometer was located about 1.8 meters (6 ft) from the ground near the southern straight section of the track. The ambient temperature readings were taken at the instrumentation trailer near the west curve of the track. During most of the test period the winds were variable and gusty.

Determination of maximum speed. - The maximum speed of the vehicle was determined in the following manner. The vehicle was fully charged and loaded to gross vehicle weight. After one warmup lap, the vehicle was driven at wide-open throttle for three laps around the track. The minimum speed for each lap was recorded and the average was calculated. This average was called the vehicle maximum speed. This speed takes into account track variability and maximum vehicle loading. This quantity was then reduced by 5 percent and called the recommended maximum cruise test speed.

Cycle timer. - The cycle timer (fig. D-8) was designed to assist the vehicle driver in accurately driving SAE schedules B, C, and D. The required test profile is permanently stored on a programmable read-only memory (PROM), which is the heart of the instrument. This profile is continuously reproduced on one needle of a dual-movement analog meter shown in the figure. The second needle is connected to the output of the fifth wheel and the driver "matches needles" to accurately drive the required schedule.

One second before each speed transition (e.g., acceleration to cruise or cruise to coast), an audio signal sounds to forewarn the driver of a change. A longer duration audio signal sounds after the idle period to emphasize the start of a new cycle. The total number of test cycles driven is stored in a counter and can be displayed at any time with a pushbutton (to conserve power).

REFERENCES

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2. Society of Automotive Engineers, Inc.: Electric Vehicle Test Procedure - SAE J227a. Feb. 1976.

3. Battronics Minivan Service and Parts Manual. Battronic Truck Corp., Boyertown, Pa.

4. Franz, Gary J.: Performance and Operation Tests of a Battery Powered Multi-Purpose Work Vehicle Manufactured by Boyertown Auto Body Works, Boyertown, Pennsylvania, for the Electric Vehicle Council, New York, New York. Dana Corp., 1973.

TABLE I - SUMMARY OF TEST RESULTS FOR BATTRONIC MINIVAN

(a) SI units

Test date	Gear	Test condition (constant speed, km/h; or driving schedule)	Wind velocity, km/h	Temperature, °C	Range, km	Cycle life, number of cycles	Current out of batteries, Ah	Current into batteries, Ah	Energy into charger, MJ	Indicated energy consumption, MJ/km
2/5/77	Low	40.2	3 2	17	105.2	—	285	330	49 6	1 70
2/9/77		40.2	8 - 13	17	106.4	—	290	335	49 1	1.66
2/6/77		59.5	0 - 9.6	18	80.8	—	246	324	49.9	2.21
3/2/77		59.5	18 - 19	14	71.8	—	238	304	46 0	2.30
3/7/77	↓	59 5	8	19	83.5	—	211	333	50 2	2 17
2/10/77	High	72 4	1.6 - 6.4	15	55 2	—	229	342	52.1	3 40
2/8/77		72 4	13 - 16	22	47.1	—	195	250	37.2	2 84
3/8/77		72.4	1 6 - 11.2	25	52.6	—	227	286	44 0	3 02
3/13/77		83 7	9.6 - 13	16	37.0	—	194	250	36.6	3.56
3/14/77	↓	83.7	13 - 14 5	10	33 8	—	184	268	42.2	4.49
3/3/77	Low	B	14.5 - 16	14	76.4	235	308	352	52 1	2 46
3/5/77		B	8	14	82 4	252	321	381	55.2	2 44
3/4/77		C	8	14	63.7	113	270	324	48.2	2 73
3/6/77	↓	C	3 2	12	63.6	118	273	364	55.0	3.11

(b) U S. customary units

Test date	Gear	Test condition (constant speed, mph; or driving schedule)	Wind velocity, mph	Temperature, °F	Range, miles	Cycle life, number of cycles	Current out of batteries, Ah	Current into batteries, Ah	Energy into charger, kWh	Indicated energy consumption, kWh/mile
2/5/77	Low	25	2	63	65.4	—	285	330	49 6	0 76
2/9/77		25	5 - 8	63	66.1	—	290	335	49.1	74
2/6/77		37	0 - 6	65	50.2	—	246	324	49.9	99
3/2/77		37	11 - 12	57	44 6	—	238	303	46 0	1.03
3/7/77	↓	37	5	67	51.9	—	211	333	50.2	.97
2/10/77	High	45	1 - 4	59	34.3	—	229	342	52.0	1.52
2/8/77		45	8 - 10	71	29.3	—	195	249	37.2	1.27
3/8/77		45	1 - 7	77	32.7	—	227	286	44.0	1.35
3/13/77		52	6 - 8	61	23.0	—	194	250	36.6	1 59
3/14/77	↓	52	8 - 9	50	21.0	—	184	268	42.2	2 01
3/3/77	Low	B	9 - 10	58	47.5	235	308	352	52.1	1.10
3/5/77		B	5	58	51.2	252	321	381	55.7	1.09
3/4/77		C	5	57	39.6	113	270	324	48 2	1.22
3/6/77	↓	C	2	53	39.5	118	273	364	55.0	1.39

TABLE II - ACCELERATION TIMES OF BATTRONIC MINIVAN

(a) In high gear

Vehicle speed		Amount of discharge, percent		
km/h	mph	0	40	80
		Time to reach designated vehicle speed, s		
0	0	0	0	0
2.0	1.2	.9	.9	2.2
4.0	2.5	1.8	1.8	3.1
6.0	3.7	2.3	2.4	3.7
8.0	5.0	2.8	2.9	4.3
10.0	6.2	3.3	3.3	4.7
12.0	7.5	3.7	3.6	5.2
14.0	8.7	4.1	4.0	5.8
16.0	9.9	4.5	4.3	6.4
18.0	11.2	4.8	4.7	7.0
20.0	12.4	5.1	5.0	7.6
22.0	13.7	5.3	5.5	8.4
24.0	14.9	5.6	5.9	9.2
26.0	16.2	5.9	6.4	10.1
28.0	17.4	6.3	6.9	11.0
30.0	18.7	6.7	7.3	12.1
32.0	19.9	7.2	7.8	13.1
34.0	21.1	7.6	8.3	14.2
36.0	22.4	8.2	9.0	15.4
38.0	23.6	8.7	9.6	16.5
40.0	24.9	9.3	10.1	17.6
42.0	26.1	9.9	10.7	18.7
44.0	27.4	10.4	11.4	19.9
46.0	28.6	10.9	12.2	21.2
48.0	29.8	11.6	13.1	22.7
50.0	31.1	12.3	14.1	24.3
52.0	32.3	13.1	15.1	26.3
54.0	33.6	14.1	16.0	28.4
56.0	34.8	15.2	17.1	31.3
58.0	36.1	16.1	18.5	34.5
60.0	37.3	17.3	20.0	38.8
62.0	38.5	18.6	21.8	45.9
64.0	39.8	20.3	23.7	----
66.0	41.0	22.2	26.0	----
68.0	42.3	24.1	28.8	----
70.0	43.8	26.7	32.4	----
72.0	44.8	30.0	36.7	----
74.0	46.0	33.8	----	----
76.0	47.2	39.0	----	----
78.0	48.5	45.6	----	----
(b) In low gear				
0	0	----	0	0
2.0	1.2	----	.6	.5
4.0	2.5	----	1.1	1.1
6.0	3.7	----	1.6	1.6
8.0	5.0	----	2.1	2.1
10.0	6.2	----	2.5	2.5
12.0	7.5	----	2.9	3.0
14.0	8.7	----	3.3	3.7
16.0	9.9	----	3.7	4.5
18.0	11.2	----	4.0	5.1
20.0	12.4	----	4.4	6.1
22.0	13.7	----	4.8	7.2
24.0	14.9	----	5.4	8.4
26.0	16.2	----	5.9	9.5
28.0	17.4	----	6.4	10.7
30.0	18.7	----	6.9	12.2
32.0	19.0	----	7.5	13.8
34.0	21.1	----	8.2	15.6
36.0	22.4	----	9.0	18.1
38.0	23.6	----	9.6	21.2
40.0	24.9	----	10.4	25.5
42.0	26.1	----	11.2	----
44.0	27.4	----	12.2	----
46.0	28.6	----	13.2	----
48.0	29.8	----	14.3	----
50.0	31.1	----	15.4	----
52.0	32.3	----	16.7	----
54.0	33.6	----	18.4	----
56.0	34.8	----	20.3	----
58.0	36.0	----	22.5	----
60.0	37.3	----	25.4	----
62.0	38.5	----	28.6	----

TABLE III. - ACCELERATION CHARACTERISTICS OF BATTRONIC MINIVAN

(a) In high gear

Vehicle speed		Amount of discharge, percent					
		0		40		80	
		Vehicle acceleration					
km/h	mph	m/s^2	mph/s	m/s^2	mph/s	m/s^2	mph/s
0	0	0	0	0	0	0	0
2 0	1.2	.63	1 41	.62	1 39	.44	.98
4.0	2.5	.84	1 88	82	1.83	.74	1.65
6.0	3.7	1.05	2 35	1 02	2.27	.97	2 18
8.0	5.0	1.12	2.50	1.21	2.71	1.21	2.71
10.0	6.2	1.24	2.77	1.52	3.39	1.18	2.64
12 0	7.5	1.37	3.07	1 65	3.69	.99	2.22
14 0	8.7	1.50	3.33	1.60	3.58	.95	2.12
16.0	9.9	1.60	3.59	1 58	3.53	.93	2 08
18.0	11.2	1.78	3.98	1.58	3 53	.90	2 02
20.0	12.4	2.19	4.89	1.44	3.23	.81	1.81
22.0	13.7	2.26	5 05	1.29	2.87	.69	1.55
24.0	14.9	1.99	4.44	1.23	2 74	63	1.40
26.0	16.2	1.66	3.72	1.16	2.60	62	1.39
28.0	17 4	1.35	3.01	1.13	2.52	.59	1.31
30.0	18.7	1 27	2.84	1.14	2.54	54	1.22
32 0	19.9	1 20	2.68	1.12	2.51	.53	1 18
34 0	21.1	1 11	2.49	1.00	2.23	.47	1.06
36.0	22 4	1.05	2.35	.87	1.96	.47	1.06
38 0	23 6	99	2 22	.97	2 16	51	1.15
40.0	24.9	94	2 10	1.06	2.37	.52	1.17
42 0	26 1	1 01	2 26	.90	2.02	.49	1.09
44.0	27 4	1 07	2 38	.72	1 60	.44	.99
46 0	28 6	91	2.02	.64	1.43	40	.90
48.0	29 8	80	1 80	.60	1.34	.36	.80
50 0	31 1	.75	1 67	.58	1 30	.31	.69
52 0	32 3	.62	1.38	.58	1.29	.27	.61
54 0	33 6	.55	1.22	54	1.21	.23	.51
56 0	34 8	.56	1 26	.45	1.01	.18	.41
58 0	36 1	.54	1 20	38	.86	15	.34
60 0	37 3	45	1 01	34	.76	.10	.23
62.0	38.5	.38	.84	.30	68	.07	.15
64.0	39.8	.31	.70	27	60	----	----
66 0	41.0	.29	.65	.22	49	----	----
68.0	42.3	.25	.56	17	.39	----	----
70.0	43.5	.19	.43	14	32	----	----
72.0	44.8	.16	.35	11	.24	----	----
74.0	46.0	.13	.28	----	----	----	----
76.0	47.2	.10	.21	----	----	----	----
78.0	48.5	09	.19	----	----	----	----

(b) In low gear

0	0	----	----	0	0	0	0
2.0	1.2	----	----	1.01	2.26	1.00	2.23
4.0	2.5	----	----	1.05	2.35	1.03	2.31
6.0	3.7	----	----	1.18	2.63	1.13	2.53
8.0	5.0	----	----	1.29	2.88	1.21	2 71
10.0	6.2	----	----	1.29	2.88	1.20	2.69
12.0	7.5	----	----	1.30	2.91	.97	2 17
14.0	8.7	----	----	1.50	3.36	.78	1.75
16.0	9.9	----	----	1.66	3 70	.80	1.79
18.0	11 2	----	----	1.52	3 40	.69	1.54
20.0	12.4	----	----	1 33	2.98	.53	1.19
22.0	13.7	----	----	1.17	2.61	.48	1.08
24.0	14.9	----	----	1.11	2.48	.50	1 12
26.0	16.2	----	----	1.10	2.47	.49	1.10
28.0	17.4	----	----	1.06	2.37	.42	.93
30.0	18.7	----	----	.97	2.17	.36	.81
32.0	19.9	----	----	.86	1 92	32	.72
34.0	21.1	----	----	.77	1 72	.26	.59
36.0	22.4	----	----	.79	1 77	20	.45
38.0	23.6	----	----	.81	1.82	16	.35
40.0	24.9	----	----	.70	1.56	.11	.26
42.0	26.1	----	----	61	1.37	----	----
44.0	27.4	----	----	.56	1.25	----	----
46 0	28 6	----	----	.52	1.16	----	----
48.0	29 8	----	----	.50	1.13	----	----
50 0	31.0	----	----	.47	1.06	----	----
52 0	32 3	----	----	38	.85	----	----
54 0	33 6	----	----	.31	.69	----	----
56.0	34.8	----	----	.27	.61	----	----
58.0	36 1	----	----	.22	.50	----	----
60 0	37.3	----	----	.18	.41	----	----
62 0	38.5	----	----	.14	.31	----	----

TABLE IV - GRADEABILITY OF BATTRONIC MINIVAN

(a) In high gear

Vehicle speed		Amount of discharge, percent		
km/h	mph	0	40	80
		Gradeability, percent		
0	0	0	0	0
2.0	1.2	6 5	6 4	4.5
4.0	2.5	8.6	8 4	7.6
6 0	3.7	10.9	10 5	10.0
8.0	5.0	11.5	12 5	12 5
10.0	6.2	12.8	15.7	12.2
12.0	7.5	14 2	17.1	10 2
14.0	8.7	15 5	16 6	9.7
16.0	9.9	16 7	16.4	9.6
18.0	11.1	18 5	16 4	9.3
20.0	12.4	23.0	15.0	8.3
22.0	13 7	23 8	13.3	7.1
24 0	14.9	20.8	12 7	6.4
26.0	16.2	17 3	12.0	6.4
28.0	17.4	13.9	11.6	6.0
30.0	18 7	13 1	11 7	5.6
32 0	19.9	12.4	11.6	5.4
34.0	21.1	11 5	10 3	4.8
36.0	22.4	10.8	9.0	4.9
38 0	23.6	10.2	10.0	5.3
40 0	24.9	9.7	10.9	5.3
42 0	26.1	10.4	9.3	5 0
44 0	27.4	11.0	7.3	4.5
46.0	28.6	9.3	6 6	4 1
48.0	29.8	8 3	6.1	3.7
50.0	31.1	7.7	5 9	3.2
52.0	32 3	6 3	5.9	2 8
54 0	33.6	5.6	5 5	2.3
56.0	34.8	5 8	4.6	1.9
58.0	36.1	5.5	3.9	1.5
60.0	37.3	4.6	3.5	1.1
62.0	38 5	3.9	3.1	.7
64.0	39 8	3 2	2.7	----
66.0	41 0	3.0	2.3	----
68 0	42.3	2.6	1.8	----
70.0	43.5	2.0	1.4	----
72 0	44.8	1.6	1 1	----
74 0	46.0	1.3	----	----
76 0	47.2	1.0	----	----
78 0	48.5	9	----	----

(b) In low gear

0	0	----	0	0
2 0	1.2	----	10.4	10 3
4 0	2.5	----	10 8	10 6
6 0	3.7	----	12 1	11.7
8.0	5 0	----	13.3	12.5
10 0	6 2	----	13 3	12.4
12 0	7.5	----	13 4	10 0
14 0	8.7	----	15.6	8 0
16.0	9.9	----	17 2	8 2
18.0	11 1	----	15.8	7 1
20.0	12 4	----	13.8	5 5
22 0	13 7	----	12.1	5 0
24 0	14.0	----	11.4	5 1
26.0	16.1	----	11 4	5 1
28 0	17.4	----	10 9	4 3
30 0	18 7	----	10 0	3.7
32 0	19.9	----	8 9	3.3
34.0	21.1	----	7 9	2 7
36.0	22.4	----	8.1	2.1
38.0	23.6	----	8 4	1 6
40.0	24 9	----	7.2	1 2
42 0	26 1	----	6 3	----
44.0	27.4	----	5.7	----
46.0	28 6	----	5.3	----
48 0	29.8	----	5.2	----
50 0	31 1	----	4.9	----
52.0	32.3	----	3.9	----
54.0	33.6	----	3 2	----
56.0	34.8	----	2.8	----
58.0	36 1	----	2.3	----
60.0	37 3	----	1 9	----
62.0	38 5	----	1.4	----

TABLE V. - ROAD ENERGY CONSUMPTION FOR BATTRONIC MINIVAN

Vehicle speed		Road energy consumed	
km/h	mph	MJ/km	kWh/mile
76.0	47.2	0	0
74.0	46.0	.79	.35
72.0	44.7	.90	.40
70.0	43.5	1.00	.45
68.0	42.3	.97	.43
66.0	41.0	.89	.40
64.0	39.8	.89	.40
62.0	38.5	.79	.35
60.0	37.3	.76	.34
58.0	36.0	.75	.33
56.0	34.8	.70	.31
54.0	33.6	.71	.32
52.0	32.3	.67	.30
50.0	31.1	.62	.28
48.0	29.8	.63	.28
46.0	28.6	.60	.27
44.0	27.3	.55	.25
42.0	26.1	.55	.24
40.0	24.9	.52	.23
38.0	23.6	.48	.22
36.0	22.4	.47	.21
34.0	21.1	.46	.20
32.0	19.9	.43	.19
30.0	18.6	.41	.18
28.0	17.4	.39	.17
26.0	16.2	.40	.18
24.0	14.9	.41	.18
22.0	13.7	.41	.18
20.0	12.4	.42	.19
18.0	11.2	.45	.20
16.0	9.9	.49	.22
14.0	8.7	.45	.20
12.0	7.5	.41	.18
10.0	6.2	.43	.19
8.0	5.0	.44	.20
6.0	3.7	.46	.21
4.0	2.5	.50	.22
2.0	1.2	.43	.19

TABLE VI. - ROAD POWER REQUIREMENTS FOR BATTRONIC MINIVAN

Vehicle speed		Road power required	
km/h	mph	kW	hp
76.0	47.2	0	0
74.0	46.0	16.3	21.9
72.0	44.7	18.0	24.1
70.0	43.5	19.4	26.0
68.0	42.3	18.3	24.6
66.0	41.0	16.4	22.0
64.0	39.8	15.7	21.1
62.0	38.5	13.6	18.2
60.0	37.3	12.7	17.0
58.0	36.0	12.1	16.2
56.0	34.8	10.8	14.5
54.0	33.6	10.6	14.2
52.0	32.3	9.7	13.0
50.0	31.1	8.7	11.6
48.0	29.8	8.4	11.3
46.0	28.6	7.7	10.3
44.0	27.3	6.7	9.0
42.0	26.1	6.4	8.5
40.0	24.9	5.8	7.8
38.0	23.6	5.1	6.8
36.0	22.4	4.7	6.4
34.0	21.1	4.3	5.8
32.0	19.9	3.8	5.2
30.0	18.6	3.4	4.5
28.0	17.4	3.0	4.0
26.0	16.2	2.9	3.9
24.0	14.9	2.7	3.6
22.0	13.7	2.5	3.4
20.0	12.4	2.3	3.1
18.0	11.2	2.2	3.0
16.0	9.9	2.2	2.9
14.0	8.7	1.8	2.4
12.0	7.5	1.4	1.8
10.0	6.2	1.2	1.6
8.0	5.0	1.0	1.3
6.0	3.7	.8	1.0
4.0	2.5	.8	.7
2.0	1.2	.2	.3

TABLE VII. - ENERGY CONSUMPTION FOR

BATTRONIC MINIVAN

Vehicle speed		Energy consumption	
km/h	mph	MJ/km	kWh/mile
40.2	25.0	1.70	0.76
40.2	25.0	1.39	.62
59.5	37.0	2.22	.99
59.5	37.0	2.17	.97
72.4	45.0	3.40	1.52
72.4	45.0	3.02	1.35
83.7	52.0	3.56	1.59
83.7	52.0	4.50	2.01

TABLE VIII. - EV-330 CELL CHARACTERISTICS

Cell height, m (in.)	0.45 (17.7)
Cell width, m (in.)	0.09 (3.5)
Cell length, m (in.)	0.16 (6.2)
Weight (trayed), kg (lbm)	21.5 (47.3)
Cell acid volume, liters (qt)	3.1 (3.3)
Number of plates per cell	13
Cycle life, number of cycles	400

TABLE B-1. - CONSTANT-BANDWIDTH CHANNELS

IN EACH REMOTE SIGNAL-CONDITIONING

MODULE FOR WATERMAN DAF

IRIG constant-bandwidth channel	Center frequency, kHz	Deviation, kHz
1A	16	+2
2A	24	
3A	32	
4A	40	
5A	48	
6A	56	
7A	64	
8A	72	
9A	80	
11B	96	+4
13B	112	
15B	128	
17B	144	
19B	160	

TABLE B-2. - DIRECT-CURRENT AMPLITUDE ACCURACY

Transducer	Parameter	Accuracy, percent
DC voltage	Tolerance	±0.4
Calibration resistors	Tolerance	±.1
Amplifier	Nonlinearity	±.5
Voltage-controlled oscillator	Nonlinearity	±.25
Recorder	Speed inaccuracy	±.01
Data demodulator	Nonlinearity	±.1

Figure 1. - Battronic Minivan.

Figure 2. - View of Battronic Minivan showing access to cargo area through rear door.

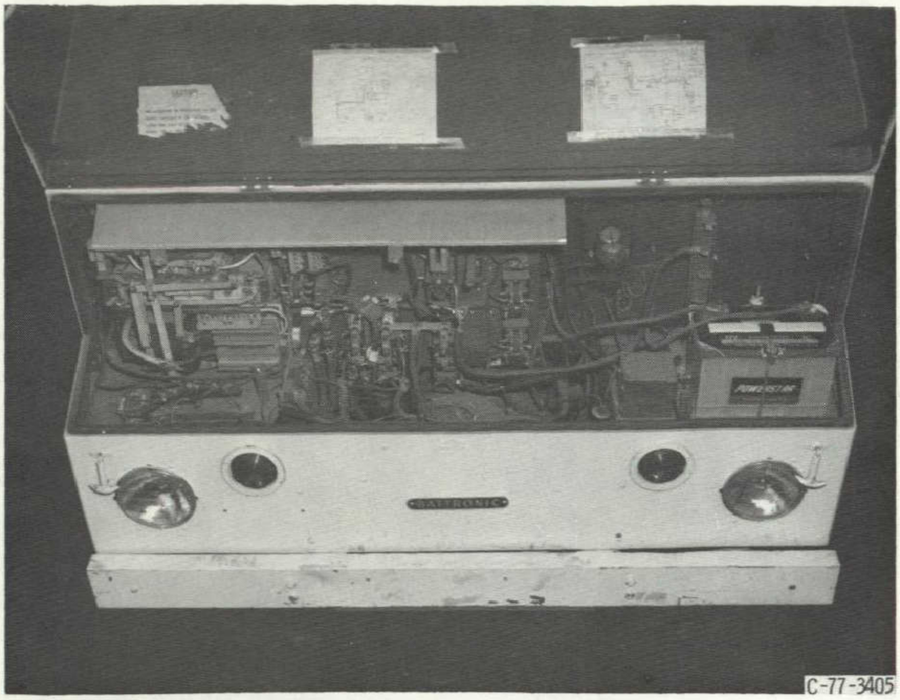


Figure 3. - View of area under front hood showing silicon-controlled-rectifier, direct-current chopper controller.

Figure 4. - View through rear door showing right battery pack. Charger is immediately in front of passenger seat.

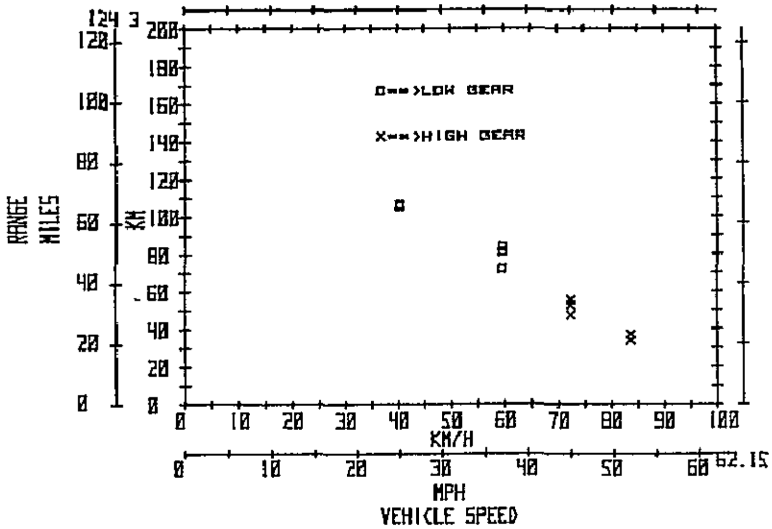
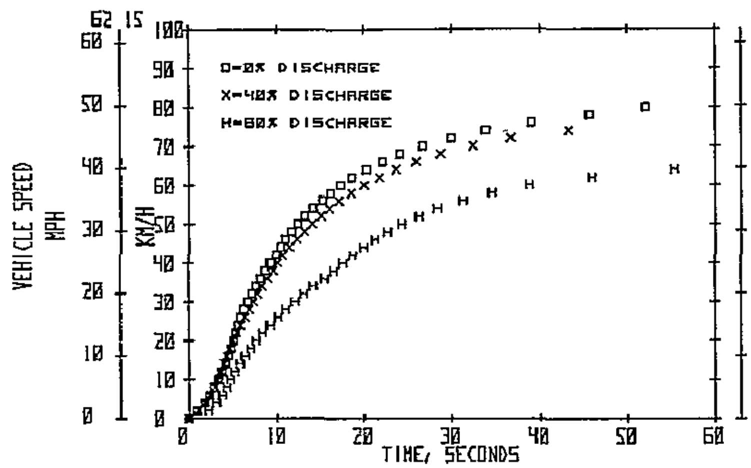
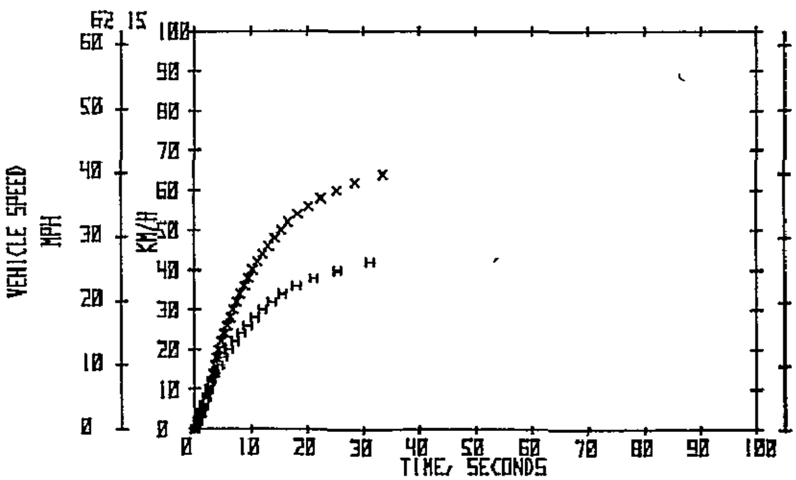


Figure 7 - Range at a constant speed for Battronic Minivan Test dates, January 17 to April 1, 1977

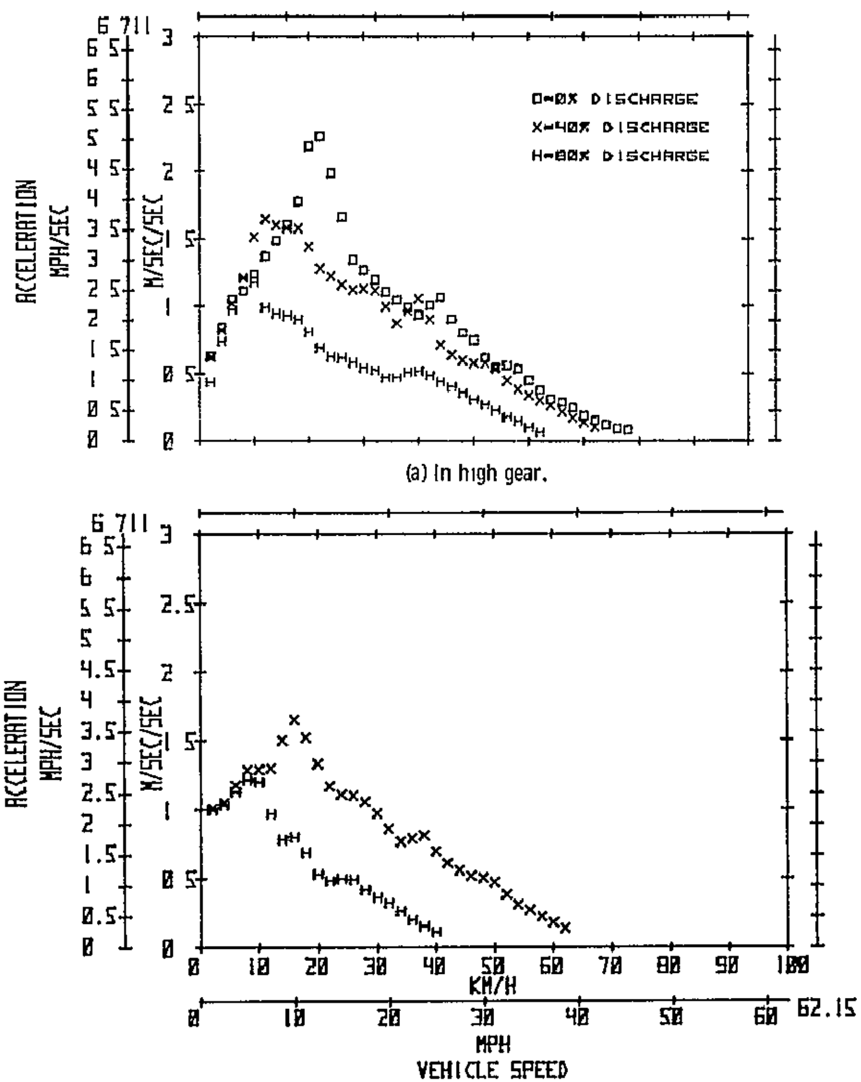


(a) In high gear



(b) In low gear.

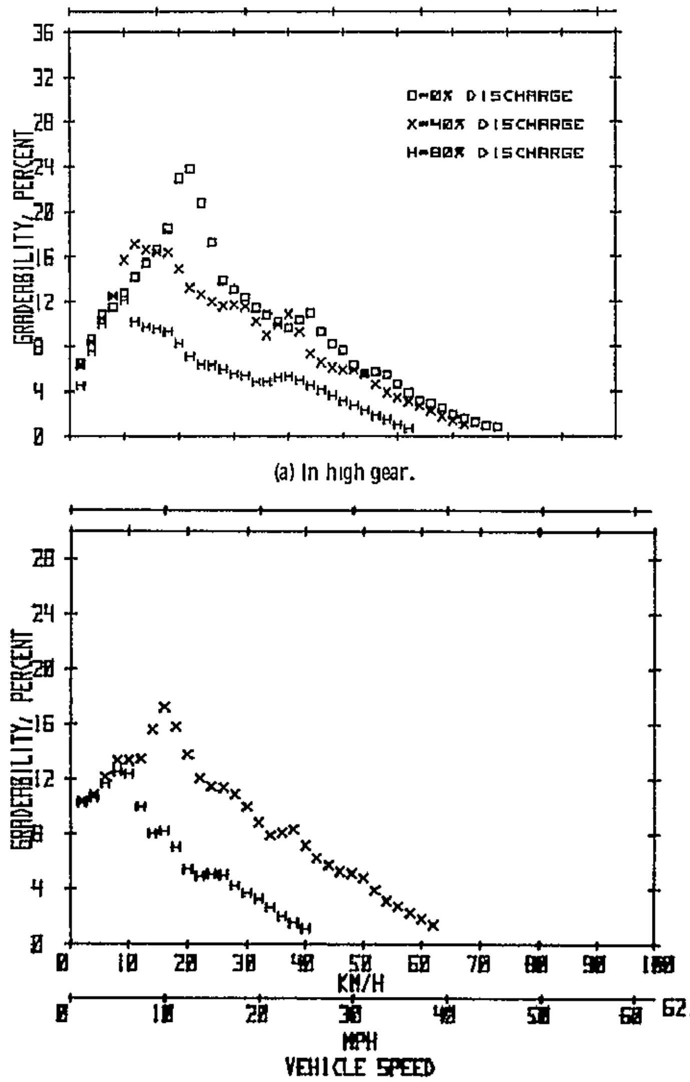
Figure 8 - Vehicle acceleration.



(a) In high gear.

(b) In low gear

Figure 9. - Acceleration as a function of speed for Battronic Minivan. Test date, March 12, 1977.



(a) In high gear.

(b) In low gear.

Figure 10. - Gradeability as a function of speed for Battronic Minivan. Test date, March 12, 1977.

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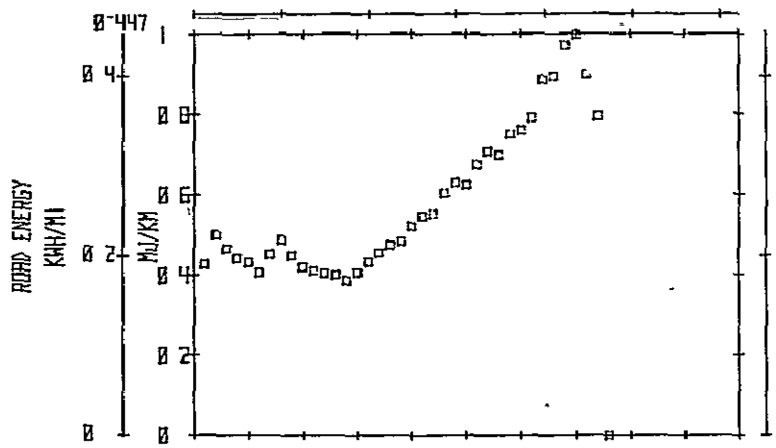

Figure 11. - Road energy as a function of speed for Battronic Minivan - high gear. Test date, March 12, 1977.

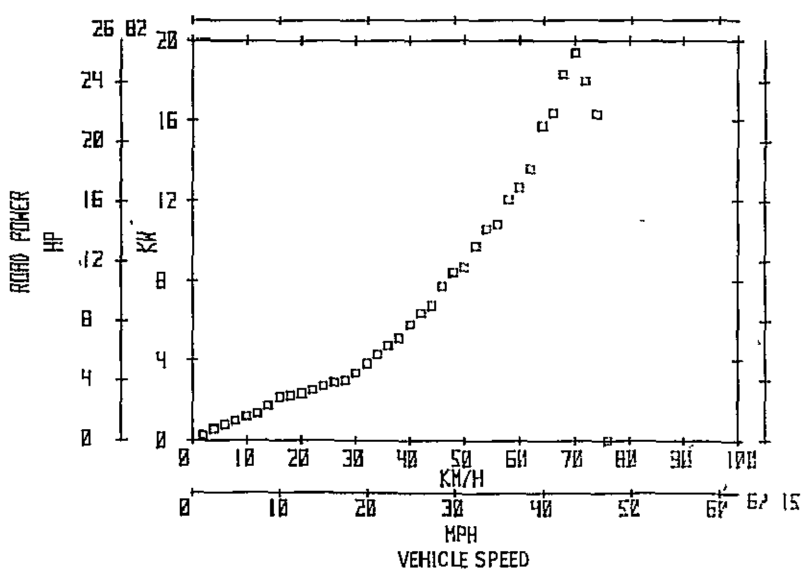

Figure 12 - Road power as a function of speed for Battronic Minivan - high gear Test date, March 12, 1977

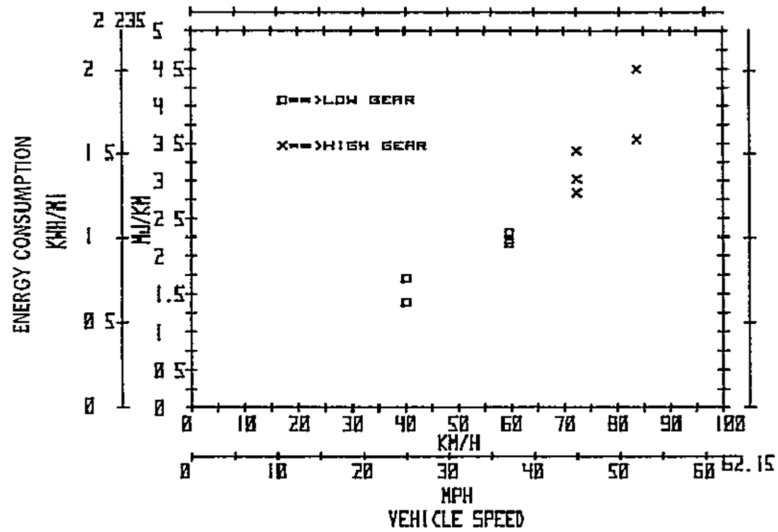

Figure 13 - Energy consumption as a function of speed for Battronic Mini-van Test dates, January 17 to April 1, 1977

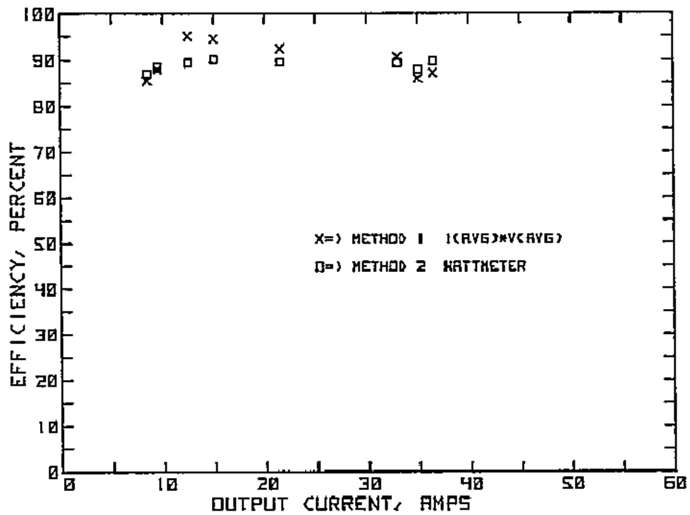

Figure 14 - Charger efficiency as a function of current for Battronic Minivan

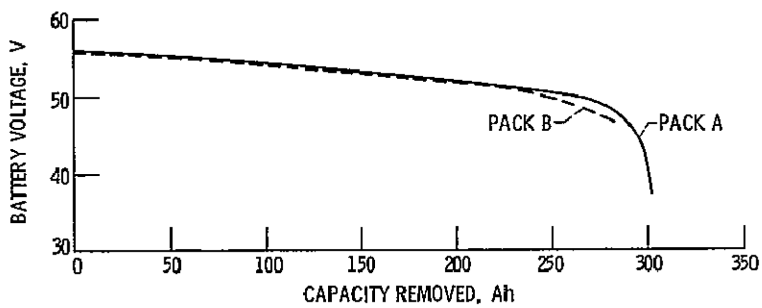

Figure 15 - Battery discharge capacity check (at a 92.4-A discharge rate)

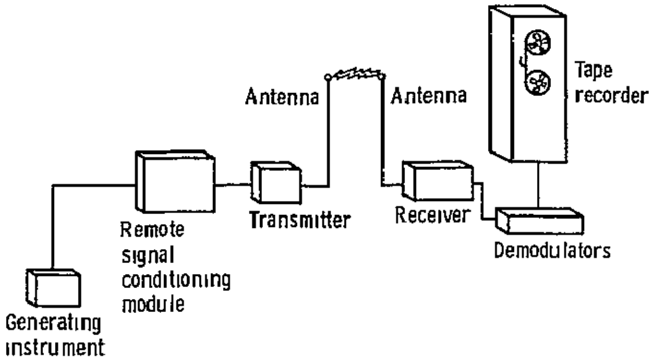

Figure B-1. - Data acquisition system schematic

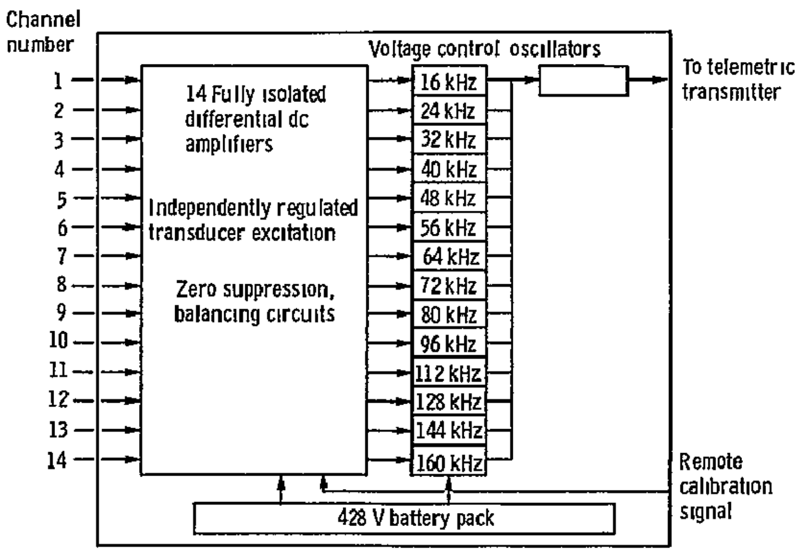

Figure B-2. - Remote signal conditioning module diagram.

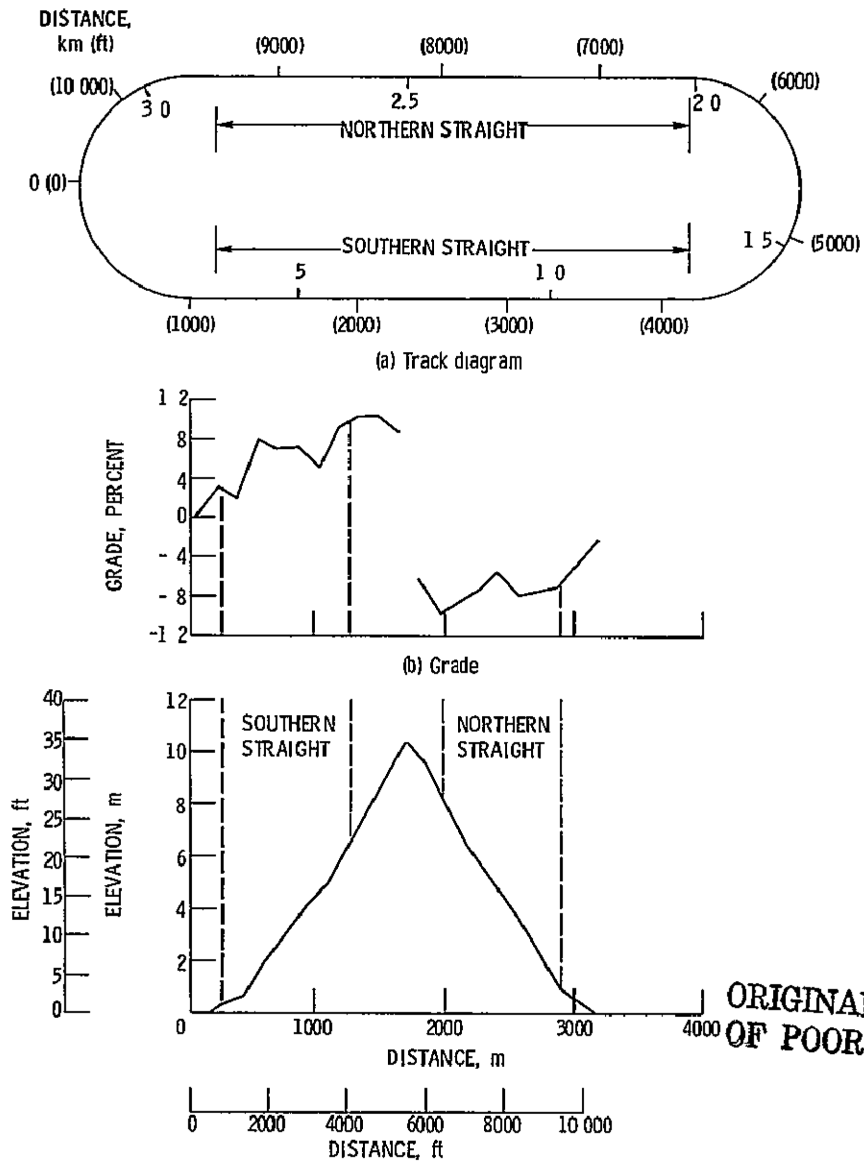

Figure C-1 - Characteristics of Dynamic Science Test Track, Phoenix, Arizona

1. Vehicle ____________________
2 Date received ____________________
3 Checked for damage - date ____________________
4 Wheel alignment - date ____________________
5 Battery checked and equalized - date ____________________
6 Curb weight determined, lbm ____________ Date ________
7 Gross vehicle weight, lbm ____________________
8 300-Ampere test - date ____________________
9. Manufacturers recommendations
   Maximum speed, mph ____________________
   Tire pressures, psi Front __________; Rear __________
   Driving procedures ____________________

Figure D-1. - Vehicle preparation check sheet.

Vehicle ____________________, ____________ mph range test, ____________ gear

Driver Instructions

1 Complete pretest checklist

2 While on track recheck
Integrator - light on, in "operate" position, zeroed
Speedometer - set on ____ mph center
Distance - on, reset, lighted
Attenuator - on, reset, lighted

3 At signal from control center accelerate moderately to ____ mph.

4. Maintain ____ ±1 mph with minimal accelerator movement

5. When vehicle is no longer able to maintain ____ mph, brake moderately to full stop.

6. Complete post-test checklist and other documentation.

Recording

1. Set oscillograph zeros at

Channel	Zero, in.
3	3.0
4	4 5
6	5 0
10	.75
12	1.1
13	1.2
14	2.0

2. Record all channels on magnetic tape Check inputs at beginning of test to verify recording.

3. Run cals on all channels

4 Remove all channels from oscillograph except 3 and 4.

5 Start recording 15 s before start of test at oscillograph speed of 0.1 in/s and tape speed of ______ in/s.

6. After 15 min into test connect channels 6, 10, 12, 13, and 14 to oscillograph and record a burst at 100 in/s while vehicle is in chopper mode.

7. Remove channels 6, 10, 12, 13, and 14 from oscillograph and continue test at 0 1 in/s with channels 3 and 4 only

8. Document all ambient conditions at beginning, once every hour, and at the end of the test Items recorded shall include temperature, wind speed and direction, significant wind gusts, and corrected barometric pressure

(a) Constant-speed test

Vehicle ____________________, ____________ cycle test, ____________ gear

Driver Instructions

1 Complete pretest checklist

2. While on track recheck.
Integrator - light on, in "operate" position, zeroed
Speedometer - set on ____ mph center
Distance - on, reset, lighted
Attenuator - on, reset, selector on 100
Cycle timer - verify scheduled timing with stop watch

3. At signal from control center, perform cycle test using cycle timer as basis for determining length of each phase of performance cycle. Use programmed stop watch as backup device. Cycle consists of

Accelerate to ______ mph in ______ s

Cruise at ______ mph for ______ s

Coast for ______ s

Brake to complete stop in ______ s

Hold in stop position for ______ s

Repeat entire cycle until vehicle is unable to meet acceleration time. Moderately brake to a complete stop.

4. Complete post-test checklist and other documentation

Recording

1. Record all channels on magnetic tape at ______ in/s Check all channels to verify input at beginning of test

2. Record speed and distance on oscillograph at ______ in/s.

3 Start recording data 15 s before beginning test

4. Document ambient conditions at beginning, once every hour, and at the end of the test Items recorded shall include temperature, wind speed and direction, significant wind gusts, and corrected barometric pressure

(b) Driving cycle test

Figure D-2 - Test checklists

1. Record specific gravity readings after removing vehicle from charge, and disconnect charger instrumentation Fill in charge data portion of data sheet from previous test Add water to batteries as necessary, recording amount added Check and record 5th wheel tire pressure and vehicle tire pressure
2. Connect· (Connect alligator clips to instrumentation battery last)
   (a) Inverter to instrument battery
   (b) Integrator input lead
   (c) Integrator power to inverter
   (d) Starred (*) 5th wheel jumper cable
   (e) Cycle timer power and speed signal input cables. Check times
   (f) Spin up and calibrate 5th wheel
3. Record test weight - includes driver and ballast with 5th wheel raised
4. Turn on.
   (a) Inverter, motor speed sensor, thermocouple reference junctions, integrator, and digital voltmeter Set integrator on "Operate."
   (b) Fifth wheel readout and switching interface units (2) (Select distance for expanded scale range)
5. Tow vehicle onto track with 5th wheel raised
   Precalibrations·
   Tape data system
   Oscillograph
   Reset.
   5th wheel distance
   Ampere-hour meter
   Thermocouple readout switches on "Record"
   Turn on thermocouple reference junctions
   Lower 5th wheel. Set hub loading.
6. Be sure data sheet is properly filled out to this point Check watch time with control tower
7. Proceed with test.

Figure D-3 - Pretest checklist

Vehicle ____ Battery system ____
Test ____ Date ____
Track data
Driver ____ Navigator ____
Average pretest specific gravity ____
Open-circuit voltage, V ____
Tire pressure before test, psi·
Right front ___ Left front ___ Right rear ___ Left rear ___
Tire pressure after test, psi
Right front ___ Left front ___ Right rear ___ Left rear ___
Fifth-wheel pressure, psi ____ (calibrated, ____ psi)

Weather:	Initial	During test	Final
Temperature, °F	____	____	____
Wind speed, mph	____	____	____
Wind direction	____	____	____
Pressure, in Hg	____	____	____

Battery temperature, °F· Before ____ After ____
Motor temperature, °F: Before ____ After ____
Time: Start ____ Stop ____
Odometer reading, miles Start ____ Stop ____
Current out, Ah ____ Current in (regenerative), Ah ____
Fifth wheel ____
Basis for termination of tests ____

Charge data
Average post-test specific gravity ____
Open-circuit voltage, V ____
Charger used ____
Charger input voltage, V ____
Battery temperature, °F Before charge ___ After charge ___
Power, kWh. Start ____ End ____ Total ____
Time: Start ____ End ____
Total charge time, min ____
Current input, Ah ____
Average specific gravity after charge ____

Approval ____

Figure D-4 - Track and charge data

1. Record time immediately at completion of test. Turn off key switch.

2. Complete track data sheet.
   (a) Odometer stop
   (b) Ampere-hour integrator
   (c) 5th wheel distance
   (d) Read temperature
   (e) Calibrate data system
   (f) Record weather data

3 Turn off inverter, thermocouple reference junctions.

4 Disconnect 12-volt instrument battery red lead

5 Raise 5th wheel.

6 Tow vehicle off track

7 Start charge procedure (specific gravities).

8 Check specific gravity on instrument battery If less than 1 220, remove from vehicle and charge to full capacity

9 Check water level in accessory batteries Add water as necessary

Figure D-5 - Post-test checklist

Vehicle ____________ Test ____________ Date ____________

Test conditions

Temperature, °F ________ Wind speed, mph ________ at ________

Barometer reading, in Hg ____________; Other ____________

Test results

Test time, h ____________

Range, miles ____________

Cycles ____________

Current out of battery, Ah ____________

Current into battery, Ah ____________

Charge time, h ____________

Power into battery, kWh ____________

Magnetic tape:

No ____________; Speed, in/s ____________

Comments ____________

Figure D-6 - Test summary sheet

Vehicle ____________ Test ____________ Date ____________

Engineer ____________

Reason for test (checkout, component check, scheduled test, etc.) ____________

____

Limitation on test (malfunction, data system problem, brake drag, etc.) ____________

____

Changes to vehicle prior to test (repair, change batteries, etc.) ____________

____

Other comments ____________

____

Evaluation of test:

Range, miles ____________

____

Current out, Ah ____________

____

Current in, Ah ____________

____

Power in, kWh ____________

Energy consumption, kWh/mile ____________

Was planned driving cycle followed? ____________

____

General comments ____________

____

____

____

____

____

____

Figure D-7. - Engineer's data sheet.

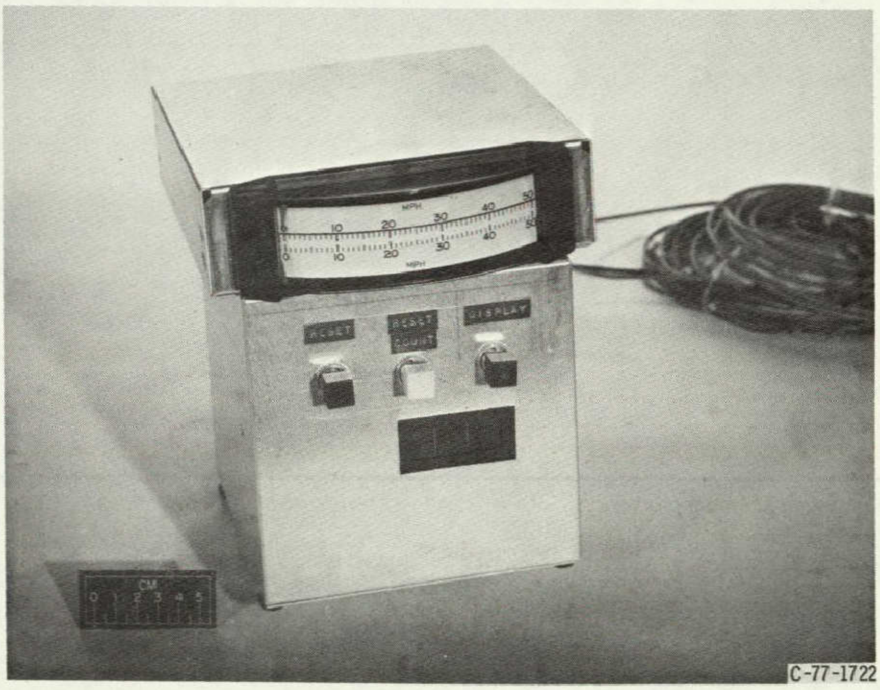

Figure D-8. - Cycle timer.

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