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BASELINE TESTS OF THE POWER-TRAIN ELECTRIC DELIVERY VAN

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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 Power-Train Van, an electric delivery van manufactured by Power-Train, Inc., Salt Lake City, Utah, was tested at the Transportation Research Center near East Liberty, Ohio, between June 15 and July 22, 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 Power-Train vehicle performance test results are presented in this report.

The Power-Train vehicle is a modified Otis P-500 utility van. It is powered by sixteen 6-volt storage batteries connected in series. A General Electric chopper controller actuated by a foot accelerator pedal changes the voltage applied to the 22-kilowatt (30-hp) series-wound drive motor. In addition to the conventional hydraulic braking system, the vehicle has hydraulic regenerative braking. Cycle tests and acceleration tests were conducted with and without hydraulic regeneration.

All tests were conducted at a gross vehicle weight of 2286 kilograms (5040 lbm). The maximum speed recommended by the manufacturer was 59 kilometers per hour (37 mph). The results of the tests are as follows:

Test speed or driving schedule		Type of test			
		Range		Energy consumption	
km/h	mph	km	mile	MJ/km	kWh/mile
40.2	25	71.5	44.4	1.24	0.55
59.5	37	61.0	37.9	1.15	.51
B[a]		51.0	31.8	----	----
B[b]		56.8	35.3	----	----
C[a]		44.6	27.7	----	----
C[b]		57.5	35.7	----	----

[a]Without hydraulic regenerative braking
[b]With hydraulic regenerative braking

The Power-Train van was able to accelerate from 0 to 32 kilometers per hour (0 to 20 mph) in 5.8 seconds and from 0 to 48 kilometers per hour (0 to 30 mph) in 12.7 seconds with

the hydraulic regenerative braking disconnected. With the hydraulic system in operation the vehicle accelerated from 0 to 32 kilometers per hour (0 to 20 mph) in 4 seconds and from 0 to 48 kilometers per hour (0 to 30 mph) in 8.5 seconds.

The Lester battery charger that was supplied by Power-Train, Inc., failed before any battery charger efficiency tests were made. Failure occurred about halfway through the test program. Another Lester charger was unavailable, so a substitute charger (Powerstat) was used during the remainder of the test program. Failure of the vehicle's differential during the first tractive force test precluded any gradeability limit or braking tests.

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. The tests were conducted according to the 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 Power-Train, Inc., the vehicle manufacturer, is 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.

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, battery charger efficiency, and battery characteristics for the Power-Train electric delivery van.

TEST VEHICLE DESCRIPTION

The Power-Train vehicle is a modified Otis P-500 utility van. It is powered by sixteen 6-volt storage batteries connected in series. A General Electric silicon-controlled rectifier (SCR) chopper controller actuated by a foot accelerator pedal changes the voltage applied to the 22-kilowatt (30-hp), series-wound drive motor. There is no transmission in the vehicle. A switch selector is provided for forward and reverse.

In addition to a conventional braking system, the vehicle has hydraulic regenerative braking, as shown in figure 1. A variable-displacement hydraulic motor is coupled to the vehicle's electric propulsion motor, which drives the wheels. During an acceleration the accelerator pedal increases the displacement of the hydraulic motor and, at the same time, through the vehicle's controller and contactor, opens the solenoid valve. This allows hydraulic pressure to open the pilot-operated check valve. High-pressure hydraulic fluid then flows from the accumulator through the hydraulic motor. A valve provides a maximum flow safety feature. It closes if the flow from the accumulator exceeds a fixed setting. A pressure switch allows the system to operate only if the accumulator pressure is greater than a fixed value.

During braking, the hydraulic motor is converted to a pump by reversing its displacement. Hydraulic fluid is pumped through the pilot-operated check valve into the accumulator. The kinetic energy of the moving vehicle is converted to high-pressure hydraulic energy as the vehicle is slowed to a stop and is stored in the accumulator until the vehicle is accelerated back up to cruising speed. The relief valve regulates the maximum pressure in the system.

A 230-volt charger mounted on a cart is provided for charging the traction batteries. A second charger mounted on the same cart charges the 12-volt accessory battery. About 16 hours is required to recharge the traction batteries from a fully discharged condition. A complete description of the vehicle is given in appendix A. The vehicle is shown in figure 2. Figure 3 is a view of the traction batteries taken through the access door under the cargo area. The hydraulic reservoir and accessory battery are at the top of the figure.

INSTRUMENTATION

Measurements taken during performance testing of the Power-Train Van included vehicle speed, distance traveled, battery current and voltage, and ampere-hours from and to the traction battery. The instrumentation package, located entirely on board the vehicle, included the following:

(1) A Honeywell 195 Electronik two-channel, strip-chart recorder: This recorder is easy to calibrate, holds calibration well, and has a high input impedance. Vehicle distance and speed were recorded continuously during each test. The accuracy of the recorder is ±0.5 percent of full scale.

(2) A Curtiss Model SHR-3 current integrator: This instrument measured integrated current into and out of the

traction battery during each test by means of a 500-ampere-per-100-millivolt current shunt. The integrator was calibrated periodically to within ±1 percent of reading.

(3) A Tripp Lite 500-watt DC/AC inverter: The inverter provided 120-volt, alternating current (AC) power to the strip-chart recorder and current integrator.

(4) A Nucleus Corporation Model NC-7 precision speedometer (fifth wheel) with a Model ERP-X1 electronic pulser for distance measurements, a Model ESS/E expanded-scale speedometer, and a programmable digital attenuator: The accuracy of the distance and velocity readings was within ±0.5 percent of readings.

(5) A 12-volt starting, lighting, and ignition (SLI) battery that supplied power to the inverter and the required 12-volt supply to the fifth-wheel components.

Battery current during the tests was measured with a 500-ampere-per-100-millivolt current shunt. All instruments were calibrated periodically. No significant shifts in calibration occurred between calibrations. The integrators and strip-chart recorders were calibrated with a Hewlett-Packard Model 6920 B meter calibrator, which has a 0.2-percent-of-reading accuracy and a usable range of 0.01 to 1000 volts. The fifth wheel was calibrated before each test by rotating the wheel on a constant-speed, fifth-wheel calibrator drum.

Measurements taken during the battery charge included (1) the current and voltage of the battery, measured with a Curtiss Model SHR-3 current integrator by means of a 500-ampere-per-100-millivolt current shunt and recorded on a Honeywell 195 Electronik two-channel, strip-chart recorder; and (2) the energy delivered to the charger, 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 Transportation Research Center of Ohio test track, a three-lane, 12-kilometer (7.5-mile) paved track located near East Liberty, Ohio. A complete description of the track is given in appendix B. When the vehicle was delivered to the test track, the pretest checks described in appendix C 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 verify the vehicle's maximum speed as recommended by the vehicle manufacturer (appendix C). All tests were run in accordance with the ERDA Electric and Hybrid Vehicle Test and Evaluation Procedure ERDA-EHV-TEP (appendix E of ref. 1) at the gross weight of the vehicle, 2286 kilograms (5040 lbm).

Range Tests at Constant Speed

The vehicle speed for the highest 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 a level track when it was traveling at full power. This speed was 59 kilometers per hour (37 mph) for the Power-Train Van.

Range tests were run at constant speeds of 40 and 59 kilometers per hour (25 and 37 mph). The speed was held constant within ±1.6 kilometers per hour (1 mph). 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 both speeds.

Range Tests under Driving Schedules

The 32-kilometer-per-hour (20-mph) schedule B and the 48-kilometer-per-hour (30-mph) schedule C stop-and-go driving cycle tests were conducted with this vehicle. These cycle tests were conducted with and without hydraulic regeneration. For the tests without hydraulic regeneration, the coupling between the traction motor and the hydraulic pump was disconnected. A complete description of 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 C. 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 pack fully charged and 40 and 80 percent discharged. Depth of discharge was determined from the number of ampere-hours removed from the batteries.

Two maximum acceleration runs in opposite directions were conducted without hydraulic regeneration at each of the three states of charge. For these tests without hydraulic regeneration, the coupling between the electric motor and the hydraulic motor was disconnected.

Coast-down tests were conducted from a maximum velocity of 59 kilometers per hour (37 mph). Two runs in opposite directions were conducted with the hydraulic regeneration coupling connected and two runs in opposite directions with the hydraulic regeneration coupling disconnected. At the beginning of each coast-down test the forward-reverse selector switch was put in neutral. The maximum acceleration and coast-down tests were conducted on the two straight sections of the test track (see appendix B).

Tractive Force Tests

The maximum grade capability of the vehicle was determined from tractive force tests by towing a second vehicle. In this type of test the driver of the towed vehicle applies the foot brake to maintain a speed of about 3 kilometers per hour (2 mph) while the test vehicle is being driven with wide-open throttle. A 13 000-newton (3000-lbf) load cell was attached to the tow chain between the vehicles.

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 watt-hour meters are calibrated for sinousoidal 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 power output 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, introducing 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 are used to determine vehicle range, battery efficiency, and energy consumption. Because air got into the hydraulic system, all constant-speed range tests were conducted with the hydraulic motor uncoupled from the drive system.

During most of the test period, the winds were variable. Even though the wind was less than 23 kilometers per hour (14 mph), on several occasions it was blowing in different directions and at different velocities at two places 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 winds were less than 23 kilometers per hour (14 mph).

The maximum speed of the vehicle recommended by the manufacturer was 59 kilometers per hour (37 mph).

Range tests at constant speed. - Range tests were run at constant speeds of 40 and 59 kilometers per hour (25 and 37 mph). 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 both speeds. The constant-speed range test results are shown in figure 4 and table I.

Range tests under driving schedules. - Two schedule B tests were run with hydraulic regenerative braking, and two without. Hydraulic regenerative braking increased the range of the schedule B tests about 11 percent. Two schedule C tests were run with hydraulic regenerative braking, and two without. Hydraulic regenerative braking increased the range of the schedule C tests about 29 percent. The variation in range for each particular test was less than 3 percent. In the schedule B tests with hydraulic regenerative braking, the highest number of cycles did not result in the longest range. Driver errors in acceleration, cruise, and braking times plus allowable instrumentation errors were the probable cause. The driving-schedule range test results are shown in table I.

Maximum Acceleration

The maximum acceleration of the vehicle was determined with the batteries fully charged and 40 and 80 percent discharged. Vehicle speed as a function of time without regenerative braking is shown in figure 5 and 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

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

After the vehicle was returned to the manufacturer, the manufacturer discovered that the hydraulic regenerative braking system had not been operating properly during the maximum acceleration tests. The maximum accelerations in terms of time to attain specific speeds with the hydraulic regenerative braking system operating properly were provided by Power-Train, Inc.

Measured acceleration time from 0 to 32 kilometers per hour (20 mph) was 5.8 seconds without hydraulic regeneration. The acceleration time provided by the manufacturer was 4.0 seconds with hydraulic regeneration. Measured acceleration time from 0 to 48 kilometers per hour (30 mph) was 12.7 seconds without hydraulic regeneration. The acceleration time provided by the manufacturer was 8.5 seconds with hydraulic regeneration.

Maximum acceleration as a function of speed at 0-, 40-, and 80-percent battery discharge without hydraulic regeneration is shown in figure 6 and table III.

Gradeability

The maximum 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

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

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 the average acceleration in meters per second squared (mph/sec).

The maximum grade that the Power-Train Van can negotiate as a function of speed at 0-, 40-, and 80-percent battery discharge without hydraulic regeneration is shown in figure 7 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 is determined by measuring the tractive force with a load cell while towing a second vehicle at about 3 kilometers per hour (2 mph). It is 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 gradeability limit tests could not be completed because the vehicle drive train failed during the first tractive force test. At the time of failure, the towed vehicle was in motion and the tractive force on the load cell was approximately 3800 newtons (900 lbf). The current drawn was 240 amperes. The gross vehicle weight was 2286 kilograms (5040 lbm).

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 by the vehicle drive train. This vehicle has no transmission so the electric motor is connected directly to the drive shaft. The drive train losses, therefore, include friction and windage losses of the electric motor. The coast-down tests were repeated with the hydraulic motor uncoupled from the drive system in order to determine the losses due to the hydraulic regenerative braking system. During the coast-down tests the differential was driven by the wheels, and thus may be different than the energy consumed when the differential is driven by the motor.

Road energy consumption E_n was calculated from the following equations:

$$E_n = 2.78\times10^{-4} W \frac{V_{n-1} - V_n}{t_n - t_{n-1}},\ \text{MJ/km}$$

or

$$E_n = 9.07\times10^{-5} W \frac{V_{n-1} - V_n}{t_n - t_{n-1}},\ \text{kWh/mile}$$

where

W   vehicle mass, kg (lbm)

V   vehicle speed, km/h (mph)

t   time, s

Average road energy consumption at 40 kilometers per hour (25 mph) was 0.43 megajoule per kilometer (0.19 kWh/mile) without hydraulic regeneration. This energy consumption increased to 0.51 megajoule per kilometer (0.23 kWh/mile) with hydraulic regeneration (a 19-percent increase).

Average road energy consumption at 56 kilometers per hour (35 mph) was 0.57 megajoule per kilometer (0.25 kWh/mile) without hydraulic regeneration. This energy consumption increased to 0.69 megajoule per kilometer (0.31 kWh/mile) with hydraulic regeneration (a 21-percent increase).

The hydraulic regenerative braking system is activated when the brake pedal is depressed. During coast-down tests, the variable-displacement hydraulic pump is near zero stroke but is still connected to the drive motor. The frictional losses associated with the hydraulic pump connected to the drive motor resulted in a higher average road energy consumption. Road energy consumption as a function of vehicle speed with and without hydraulic regeneration is shown in figure 8 and table V. Vehicle speed as a function of time during coast-down with and without hydraulic regeneration is shown in figure 9 and table VI.

Road Power Requirements

The calculation of road power is analogous to the calculation of road energy. It is a measure of the power needed to overcome vehicle aerodynamic and rolling resistance plus the power losses from the drive train. This vehicle has no transmission. The drive train losses, therefore, included friction and windage losses at the motor. The road power P_n required to propel a vehicle at various speeds was also determined from the coast-down tests. The following equations were used:

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

or

$$P_n = 6.08\text{x}10^{-5}W \frac{V_{n-1}^2 - V_n^2}{t_n - t_{n-1}}, \text{ hp}$$

Average road power at 40 kilometers per hour (25 mph) was 4.76 kilowatts without hydraulic regeneration. This average road power increased to 5.65 kilowatts with hydraulic regeneration (a 19-percent increase). Average road power at 56 kilometers per hour (35 mph) was 8.82 kilowatts without hydraulic regeneration. This average road power increased to 10.65 kilowatts with hydraulic regeneration (a 21-percent increase).

The reasons for the increase in the required road power with hydraulic regeneration are the same as those discussed under road energy consumption. The average road power as a function of speed is shown in figure 10 and table VII.

Indicated Energy Consumption

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

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 cells of the battery pack were fully charged and equalized. The reported energy usage may be higher than would be experienced with normal vehicle field operation. The average energy consumption at 40 kilometers per hour (25 mph) was 1.24 megajoules per kilometer (0.55 kWh/mile). The average energy consumption at 59 kilometers per hour (37 mph) was 1.15 megajoules per kilometer (0.51 kWh/mile). Indicated energy consumption as a function of speed is presented in figure 11 and table VIII for the constant speed tests.

VEHICLE RELIABILITY

The Power-Train vehicle was reliable during the first phases of the test program. No significant problems occurred during the schedule B, schedule C, 40-kilometer-per-hour (25-mph) range, 59-kilometer-per-hour (37-mph) range, maximum acceleration, and coast-down tests. The Lester battery charger supplied with the vehicle failed before any charger efficiency tests were made. No replacement was available so a standard Powerstat charger was used for the rest of the program. Failure of the axial drive train during the tractive force tests terminated the test program. The failure precluded braking tests.

COMPONENT PERFORMANCE AND EFFICIENCY

Battery Charger

The Lester battery charger furnished with the Power-Train vehicle is an SCR charger with solid-state regulation and charge termination circuits. The charger turns off automatically when the batteries are fully charged. A typical battery charger profile is shown in figure 12, where the charger output current and voltage are shown as a function of time. The power output of the charger is also shown as a function of time in figure 13.

Charger efficiency tests were not conducted because of a failure in the charger.

Battery Characteristics

Manufacturer's data. - The battery supplied with the Power-Train vehicle comprised 16 Trojan Battery Co. lead-acid batteries, type J-244W. The 244W battery is a 6-volt, three-cell module rated at 130 minutes discharge at a current of 75 amperes to a voltage cutoff of 1.75 volts per cell at a temperature of 25° C (77° F). Dimensional specifications as supplied by battery manufacturers are shown in table IX.

Battery acceptance. - Prior to the road tests, the battery supplied by the vehicle manufacturer was tested for battery capacity and terminal integrity.

The capacity check was performed on the battery using a constant-current load bank. Figure 14 shows the battery voltage as a function of capacity removed, at a 75-ampere rate, to a voltage cutoff of 84 volts. The capacity removed was 161.6 ampere-hours, or 99 percent of the rated capacity. As a result the battery was acceptable since it delivered more than 80 percent of the manufacturer's rated capacity.

The 300-ampere discharge test was run with a constant-current load bank. At the end of the 5-minute discharge test, the terminal temperature was measured by a thermocouple probe. As the temperature did not exceed 60 degrees Celsius above ambient, the battery system was within specification.

Battery performance at constant vehicle speed. - During the road tests, battery current and voltage were constantly monitored. The battery characteristics during the 40-kilometer-per-hour (25-mph) range test and the 59.5-kilometer-per-hour (37-mph) range test are presented in figures 15 to 17. The average battery current, voltage, and power during the first 25 percent and last 25 percent of the vehicle's range are shown in these figures. Battery power decreases toward the end of the test, probably due to the reduced power requirements as the temperatures of the mechanical drive train, tires, and associated lubricants rise during the test.

Battery performance under driving schedules. - The vehicle speed, battery voltage, current, and power for the various cycle tests with and without regenerative braking are shown in figure 18 and table X. Data are shown for two cycles of each test, one near the beginning and one near the end of the test.

Battery performance at maximum acceleration. - The battery current, voltage, and power as a function of gradeability during the maximum acceleration tests with batteries fully charged and 40 and 80 percent discharged and without the regenerative system operative are shown in figure 19 and table XI.

Charger and battery efficiency. - One battery charging phase was fully analyzed to determine battery efficiency. This charge followed the 59-kilometer-per-hour (37-mph) constant-speed test on 2/8/77. The battery charger, voltage, current, and power as a function of time are shown in figures 12 and 13.

Total energy input to the battery during charging was 19.1 kilowatt-hours; the energy removed during the 59-kilometer-per-hour (37-mph) range test was 13.5 kilowatt-hours.

The battery energy efficiency was 71 percent with an ampere-hour overcharge of 19 percent. The overcharge was provided to insure equalization of the battery and to maximize the vehicle performance in subsequent tests. In field use, a more desirable overcharge would be 10 percent, which would result in a battery energy efficiency of 76 percent.

Controller

The controller in the Power-Train Van is a General Electric silicon-controlled rectifier (SCR) chopper rated at 150 volts and 300 amperes. The controller can go into a bypass mode for maximum power that allows the current to bypass the SCR's. The bypass is initiated by pushing the accelerator to the floor. After 35 seconds the controller goes into the bypass mode and will remain in this mode until the operator lifts his foot from the floor.

Electric Motor

The Otis motor used in the Power-Train vehicle is a conventional DC series-wound traction motor originally designed for an industrial truck application. The motor was manufactured by the Baker Division of the Otis Elevator Co. The motor is rated for 96 volts and 300 amperes. The power rating is 22 kilowatts (30 hp). The insulation is class H.

The limited motor performance test data that were furnished by the motor manufacturer are presented in table XII. The tests were performed on a prototype motor using a DC power supply and other than a chopper controller. For these reasons the test results are not necessarily representative of the motor with the controller in the Power-Train vehicle.

APPENDIX A

VEHICLE SUMMARY DATA SHEET

1.0 Vehicle manufacturer Power-Train, Inc.
Salt Lake City, Utah

2.0 Vehicle Power-Train Van

3.0 Price and availability on request

4.0 Vehicle weight and load

4.1	Curb weight, kg (lbm)	1946 (4290)
4.2	Gross vehicle weight, kg (lbm)	2286 (5040)
4.3	Cargo weight, kg (lbm)	204 (450)
4.4	Number of passengers	1
4.5	Payload, kg (lbm)	340 (750)

5.0 Vehicle size

5.1	Wheelbase, m (in.)	2.46 (97)
5.2	Length, m (ft)	3.51 (11.5)
5.3	Width, m (ft)	1.57 (5.2)
5.4	Height, m (in.)	
5.5	Head room, m (in.)	1.09 (43)
5.6	Leg room, m (in.)	0.61 (24)
5.7	Frontal area, m^2 (ft^2)	
5.8	Road clearance, m (in.)	
5.9	Number of seats	2

6.0 Auxiliaries and options

6.1 Lights (number, type, and function) 2 head; 2 park and tail; 2 brake; 2 front parking; 2 license plate

6.2 Windshield wipers 2 on front windshield

6.3 Windshield washers yes

6.4 Defroster electric convection type on driver's side

6.5 Heater electric, with fan

6.6 Radio no

6.7 Fuel gage voltmeter

6.8 Amperemeter yes

6.9 Tachometer no

6.10 Speedometer yes, in mph

6.11 Odometer yes, in miles

6.12 Right- or left-hand drive right

6.13 Transmission none

6.14 Regenerative braking hydraulic

6.15 Mirrors rearview; 2 outside

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 lead acid; Trojan 224; Trojan Battery Co.

7.1.2 Number of modules 16

7.1.3 Number of cells 48

7.1.4 Operating voltage, V 96

7.1.5 Capacity, Ah 162

7.1.6 Size of each module, m (in.) height, 0.26 (10.25); width, 0.18 (7.00); length, 0.26 (10.25)

7.1.7 Weight, kg (lbm) 583 (1280)

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

7.2 Auxiliary battery

7.2.1 Type and manufacturer lead-acid SLI

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.)

7.2.6 Weight, kg (lbm)

8.0 Controller

8.1 Type and manufacturer SCR chopper with bypass; General Electric Model 310

8.2 Voltage rating, V 150

8.3 Current rating, A 300

8.4 Size, m (in.)

8.5 Weight, kg (lbm)

9.0 Propulsion motor

9.1 Type and manufacturer DC series; Baker Division of Otis Elevator Co.

9.2 Insulation class H

9.3 Voltage rating, V 96

9.4 Current rating, A 300

9.5 Horsepower (rated), kW (hp) 22 (hp)

9.6 Size, m (in.) diameter, 0.30 (11.8); length, 0.5 (20)

9.7 Weight, kg (lbm) 113 (250)

9.8 Speed (rated), rpm 3000 (max. unknown)

10.0 Battery charger

10.1 Type and manufacturer 208 V, single phase; Lester Equipment Manufacturing Co., Inc.

10.2 On- or off-board type off board

10.3 Input voltage required, V 230 AC

10.4 Peak current demand, A 24

10.5 Recharge time, h 16

10.6 Size, m (in) height, 0.301 (12); width, 0.292 (11.5); 0.368 (14.5)

10 7 Weight, kg (lbm) 22.7 (50)

10 8 Automatic turnoff feature yes, timer

11 0 Body

11.1 Manufacturer and type Power-Train, Inc., van

11 2 Materials fiberglass

11 3 Number of doors and type 2; sliding

11.4 Number of windows and type 8; safety glass windshield

11.5 Number of seats and type 2; bucket

11 6 Cargo space volume, m^3 (ft^3) 1.83 (61)

11 7 Cargo space dimensions, m (ft) 0.95×1.24×1.46 (37.5×49×57.5)

12 0 Chassis

12.1 Frame

12.1 1 Type and manufacturer welded construction

12.1 2 Materials steel

12.1.3 Modifications

12 2 Springs and shocks

12 2.1 Type and manufacturer leaf springs

12.2 2 Modifications none

12 3 Axles

12 3.1 Manufacturer

12 3.2 Front independent

12.3 3 Rear conventional differential

12.4 Transmission

12 4.1 Type and manufacturer none

12 4.2 Gear ratios ______

______

12 4.3 Driveline ratio 5.17

12.5 Steering

12 5.1 Type and manufacturer ______

______

12.5.2 Turning ratio ______

12.5.3 Turning diameter, m (ft) ______

12.6 Brakes

12 6.1 Front hydraulic drum

12 6.2 Rear hydraulic drum

12 6.3 Parking mechanical, on rear wheels

12.6.4 Regenerative hydraulic

12 7 Tires

12 7 1 Manufacturer and type Uniroyal radial

______

12 7.2 Size 175SR13

12.7.3 Pressure, kPa (psi):

Front 262 (38)

Rear 262 (38)

12 7.4 Rolling radius, m (in.) ______

12.7 5 Wheel weight, kg (lbm):

Without drum ______

With drum ______

12 7.6 Wheel track, m (in.):

Front ______

Rear ______

13 0 Performance

13 1 Manufacturer-specified maximum speed (wide-open throttle), km/h (mph) 60 (37)

13.2 Manufacturer-recommended maximum cruise speed (wide-open throttle), km/h (mph) 60 (37)

13.3 Tested at cruise speed, km/h (mph) 60 (37); 40 (25)

______

APPENDIX B

DESCRIPTION OF VEHICLE TEST TRACK

All the tests were conducted at the Transportation Research Center (TRC) of Ohio (fig. B-1). This facility was built by the State of Ohio and is now operated by a contractor and supported by the state. It is located 72 kilometers (45 miles) northwest of Columbus along U.S. route 33 near East Liberty, Ohio.

The test track is a 12-kilometer (7.5 mile) continuous loop 1.6 kilometers (1 mile) wide and 5.6 kilometers (3.5 miles) long. Three concrete lanes 11 meters (36 ft) wide in the straightaways and 13 meters (42 ft) wide in the curves make up the high-speed test area. The lanes were designed for speeds of 129, 177, and 225 kilometers per hour (80, 110, and 140 mph) with zero lateral acceleration in the curves. The 3-kilometer- (1.88-mile-) long straightaways are connected to the constant 731-meter- (2400-ft-) radius curves by a short variable-radius transition section. Adjacent to the inside concrete lane is a 3.66-meter- (12-ft-) wide asphalt berm. This berm is only banked slightly to provide a drainage slope. An additional asphalt lane 3.66 meters (12 ft) wide is located adjacent to the outside lane on the straightaways. The constant-speed and cycle tests were conducted on the inside asphalt lane because all tests were at relatively low speeds. The acceleration and coast-down tests were conducted on the straight outside asphalt lanes because these were more alike than the two inside asphalt lanes and because it was the portion of the track least likely to encounter traffic interference. The track has a constant 0.228 percent north-to-south downslope. The TRC complex also has a 20-hectare (50-acre) vehicle dynamics area and a 2740-meter- (9000-ft-) long skid pad for the conduct of braking and handling tests.

APPENDIX C

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 C-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 C-2.

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

Data taken before, during, and after each test were entered on the vehicle data sheet (fig. C-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. C-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. 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. C-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. C-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 3 meters (10 ft) from the ground within the oval.

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. The vehicle was driven at wide-open throttle for one lap around the track. The minimum speed for the 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. C-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

1. Sargent, Noel B., Maslowski, Edward A.; Soltis, Richard F.; and Schuh, Richard M.: Baseline Tests of the C. H. Waterman DAF Electric Passenger Vehicle. NASA TM-73757, 1977.

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

TABLE I. - SUMMARY OF TEST RESULTS FOR POWER-TRAIN VAN

(a) SI units

Test date	Test condition (constant speed, km/h; or driving schedule)	Wind velocity, km/h	Temperature, ^{o}C	Range, km	Cycle life, number of cycles	Current out of batteries, Ah	Current into batteries, Ah	Energy into charger, MJ	Remarks
7/6/77	40.2	8 - 13	32	73.7	—	145	191	104	—
7/11/77	40.2	5	20 - 21	69.5	—	137	174	94	—
7/18/77	40.2	8 - 16	24 - 27	71.3	—	141	231	126	—
7/8/77	59.2	5 - 6	23	60.2	—	123	146	83	—
7/12/77	59.2	6 - 13	26	61.8	—	128	154	83	—
6/23/77	B	5 - 11	24	56.0	158	148	193	104	With hydraulic regenerative braking
6/28/77	B	8 - 18	24 - 25	57.6	154	153	195	108	↓
6/24/77	C	5 - 13	26 - 27	57.6	87	140	180	101	↓
6/29/77	C	18 - 23	24	57.3	87	149	183	101	↓
6/30/77	B	13	24	51.2	140	152	199	108	Gusts to 23 km/h (14 mph); regenerative braking disconnected
7/13/77	B	5 - 10	27 - 28	51.2	138	149	193	112	Regenerative braking disconnected
7/5/77	C	8	30 - 31	44.9	69	129	181	101	Gusts to 18 km/h (11 mph); regenerative braking disconnected
7/15/77	C	6 - 11	29 - 30	44.1	69	128	186	94	Regenerative braking disconnected

(b) U.S. customary units

Test date	Test condition (constant speed, mph; or driving schedule)	Wind velocity, mph	Temperature, ^{o}F	Range, miles	Cycle life, number of cycles	Current out of batteries, Ah	Current into batteries, Ah	Energy into charger, kWh	Remarks
7/6/77	25	5 - 8	89	45.8	—	145	191	29	—
7/11/77	25	3	68 - 70	43.2	—	137	174	26	—
7/8/77	25	5 - 10	76 - 80	44.3	—	141	231	35	—
7/8/77	37	3 - 4	74	37.4	—	123	146	23	—
7/12/77	37	4 - 8	78	38.4	—	128	154	23	—
6/23/77	B	3 - 7	75	34.8	158	148	193	29	With hydraulic regenerative braking
6/28/77	B	5 - 11	75 - 77	35.8	154	153	195	30	↓
6/24/77	C	3 - 5	79 - 81	35.8	87	140	180	28	↓
6/29/77	C	11 - 14	75	35.6	87	149	183	28	↓
6/30/77	B	8	75	31.8	140	152	199	30	Gusts to 23 km/h (14); regenerative braking disconnected
7/13/77	B	3 - 6	80 - 82	31.8	138	149	193	31	Regenerative braking disconnected
7/5/77	C	5	86 - 88	27.9	69	129	181	28	Gusts to 18 km/h (11 mph); regenerative braking disconnected
7/15/77	C	4 - 7	84 - 86	27.4	69	128	186	26	Regenerative braking disconnected

TABLE II. - ACCELERATION TIMES FOR POWER-TRAIN VAN WITHOUT REGENERATIVE BRAKING

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	.6	.5	.4
4.0	2.5	.9	.8	.8
6.0	3.7	1.3	1.2	1.2
8.0	5.0	1.7	1.7	1.6
10.0	6.2	2.2	2.2	2.2
12.0	7.5	2.6	2.5	2.5
14.0	8.7	2.8	2.7	2.8
16.0	9.9	3.0	2.9	3.1
18.0	11.2	3.2	3.2	3.4
20.0	12.5	3.5	3.4	3.7
22.0	13.7	3.7	3.7	4.1
24.0	14.9	4.0	4.1	4.6
26.0	16.2	4.4	4.5	5.0
28.0	17.4	4.8	4.9	5.6
30.0	18.6	5.3	5.4	6.1
32.0	19.9	5.8	5.9	6.8
34.0	21.1	6.3	6.6	7.6
36.0	22.4	7.0	7.3	8.5
38.0	23.6	7.7	8.0	9.4
40.0	24.9	8.5	9.0	10.5
42.0	26.1	9.4	9.9	11.7
44.0	27.4	10.3	11.1	13.1
46.0	28.6	11.4	12.3	14.7
48.0	29.8	12.7	13.8	16.7
50.0	31.0	14.2	15.2	18.7
52.0	32.3	15.9	17.3	20.8
54.0	33.6	17.9	19.4	23.9
56.0	34.8	19.8	21.8	27.4

TABLE III. - ACCELERATION CHARACTERISTICS OF POWER-TRAIN VAN WITHOUT REGENERATIVE BRAKING

Time, s	Amount of discharge, percent					
	0		40		80	
	Vehicle acceleration					
	m/s^2	mph/s	m/s^2	mph/s	m/s^2	mph/s
0	0	0	0	0	0	0
.6	1.23	2.76	1.33	2.98	1.44	3.23
.9	1.47	3.29	1.42	3.18	1.41	3.16
1.3	1.39	3.11	1.29	2.89	1.31	2.92
1.7	1.20	2.69	1.18	2 64	1.19	2.66
2.2	1.28	2.85	1.47	3.28	1.27	2.84
2.6	2.35	5.25	2.10	4.71	1.71	3.83
2.8	2.90	6.48	2.52	5.65	1.93	4.31
3.0	2.50	5.59	2.46	5.51	2.07	4.62
3.2	2.17	4.86	2.26	5.05	1.86	4.18
3.5	2.27	5.07	1.96	4 39	1.49	3.34
3.7	2.28	5.10	1.63	3.65	1.35	3.01
4.0	1.66	3.72	1.48	3.31	1.21	2.71
4.4	1.45	3.25	1.38	3.11	1.12	2.50
4.8	1.35	3.03	1.26	2.82	1.01	2.25
5.3	1.15	2.57	1.10	2.47	.88	1.98
5.8	1.03	2.29	.96	2 14	.75	1.68
6.3	.93	2.08	.84	1.87	.66	1.48
7.0	.85	1.89	.75	1.68	.63	1.40
7.7	.75	1.68	.66	1.46	.56	1.25
8.5	.66	1.46	.58	1.31	.48	1.07
9.4	.60	1.35	.53	1.20	.43	.96
10.3	.55	1.23	.47	1.05	.38	.84
11.4	.47	1.04	.41	.92	.32	.71
12.7	.39	.88	.39	.88	.28	.63
14.2	.35	.79	.33	.74	.27	.60
15.9	.30	.69	.26	.59	.22	.49
17.9	.28	.63	.24	.55	.17	.38
19.8	.24	.55	.22	.50	.14	.32

TABLE IV. - GRADEABILITY OF POWER-TRAIN

VAN WITHOUT REGENERATIVE BRAKING

Velocity		Amount of discharge, percent		
km/h	mph	0	40	80
		Gradeability, percent		
0	0	0	0	0
2.0	1.2	12.7	13.8	15.0
4.0	2.5	15.2	14.8	14.6
6.0	3.7	14.4	13.4	13.5
8.0	5.0	12.4	12.2	12.3
10.0	6.2	13.2	15.2	13.1
12.0	7.5	24.8	22.1	17.8
14.0	8.7	31.1	26.8	20.1
16.0	9.9	26.5	26.1	21.7
18.0	11.2	22.8	23.8	19.5
20.0	12.5	23.9	20.5	15.5
22.0	13.7	24.0	16.9	13.9
24.0	14.9	17.3	15.3	12.5
26.0	16.2	15.0	14.4	11.5
28.0	17.4	14.0	13.0	10.8
30.0	18.6	11.8	11.4	9.1
32.0	19.9	10.6	9.8	7.7
34.0	21.1	9.6	8.6	6.8
36.0	22.4	8.7	7.7	6.4
38.0	23.6	7.7	6.7	5.8
40.0	24.9	6.7	6.0	4.9
42.0	26.1	6.2	5.5	4.4
44.0	27.4	5.7	4.8	3.9
46.0	28.6	4.8	4.2	3.2
48.0	29.8	4.0	4.0	2.9
50.0	31.0	3.6	3.4	2.8
52.0	32.3	3.2	2.7	2.2
54.0	33.6	2.9	2.5	1.7
56.0	34.8	2.5	2.3	1.4

TABLE V. - ROAD ENERGY CONSUMPTION OF POWER-TRAIN VAN

(a) With regenerative braking

Vehicle speed		Road energy consumed	
km/h	mph	MJ/km	kWh/mile
58.0	36.0	0	0
56.8	34.8	.68	.31
54.0	33.6	.66	.30
52.0	32.3	.63	.28
50.0	31.0	.50	.27
48.0	29.8	.56	.25
46.0	28.6	.57	.25
44.0	27.4	.57	.25
42.0	26.1	.53	.24
40.0	24.9	.51	.23
38.0	23.6	.50	.22
36.0	22.4	.46	.21
34.0	21.1	.44	.20
32.0	19.9	.44	.20
30.0	18.6	.43	.19
28.0	17.4	.44	.20
26.0	16.2	.42	.19
24.0	14.9	.40	.18
22.0	13.7	.40	.18
20.0	12.5	.35	.16
18.0	11.2	.33	.15
16.0	9.9	.34	.15
14.0	8.7	.34	.15
12.0	7.5	.32	.14
10.0	6.2	.31	.14
8.0	5.0	.29	.13
6.0	3.7	.29	.13
4.0	2.5	.30	.13
2.0	1.2	.31	.14

(b) Without regenerative braking

Vehicle speed		Road energy consumed	
km/h	mph	MJ/km	kWh/mile
58.0	36.0	0	0
56.0	34.8	.56	.25
54.0	33.6	.55	.25
52.0	32.3	.53	.24
50.0	31.0	.50	.22
48.0	29.8	.50	.22
46.0	28.6	.49	.22
44.0	27.4	.47	.21
42.0	26.1	.45	.20
40.0	24.9	.42	.19
38.0	23.6	.42	.19
36.0	22.4	.41	.19
34.0	21.1	.39	.17
32.0	19.9	.37	↓
30.0	18.6	.38	↓
28.0	17.4	.37	↓
26.0	16.2	.34	.15
24.0	14.9	.34	.15
22.0	13.7	.32	.15
20.0	12.5	.31	.14
18.0	11.2	.31	↓
16.0	9.9	.30	↓
14.0	8.7	.30	↓
12.0	7.5	.29	.13
10.0	6.2	.26	.12
8.0	.50	.26	↓
6.0	3.7	.26	↓
4.0	2.5	.27	↓
2.0	1.2	.26	↓

TABLE VI. - COAST-DOWN DATA FOR POWER-TRAIN VAN

(a) With regenerative braking

Time, s	Vehicle speed	
	km/h	mph
0	58.0	36.0
1.9	56.0	34.8
3.7	54.0	33.6
5.7	52.0	32.3
7.7	50.0	31.0
10.0	48.0	29.8
12.2	46.0	28.6
14.4	44.0	27.4
16.7	42.0	26.1
19.3	40.0	24.9
21.7	38.0	23.6
24.3	36.0	22.4
27.2	34.0	21.1
30.1	32.0	19.9
33.0	30.0	18.6
36.0	28.0	17.4
38.8	26.0	16.2
42.1	24.0	14.9
45.1	22.0	13.7
48.5	20.0	12.5
52.3	18.0	11.2
56.1	16.0	9.9
59.8	14.0	8.7
63.6	12.0	7.5
67.6	10.0	6.2
71.6	8.0	5.0
76.2	6.8	3.7
80.4	4.0	2.5
84.6	2.0	1.2

(b) Without regenerative braking

Time, s	Vehicle speed	
	km/h	mph
0	58.0	36.0
2.2	56.0	34.8
4.5	54.0	33.6
6.8	52.0	32.3
9.2	50.0	31.0
11.8	48.0	29.8
14.3	46.0	28.6
17.0	44.0	27.4
19.7	42.0	26.1
22.6	40.0	24.9
25.6	38.0	23.6
28.6	36.0	22.4
31.7	34.0	21.1
35.1	32.0	19.9
38.5	30.0	18.6
41.7	28.0	17.4
45.4	26.0	16.2
49.2	24.0	14.9
52.8	22.0	13.7
56.9	20.0	12.5
60.9	18.0	11.2
65.0	16.0	9.9
69.2	14.0	8.7
73.3	12.0	7.5
77.9	10.0	6.2
82.9	8.0	5.0
87.4	6.0	3.7
92.4	4.0	2.5
96.7	2.0	1.2

TABLE VII. - ROAD POWER REQUIREMENTS OF POWER-TRAIN VAN

(a) With regenerative braking

Vehicle speed		Road power required	
km/h	mph	kW	hp
58.0	36.0	0	0
56.0	34.8	10.6	14.3
54.0	33.6	10.0	13.4
52.0	32.3	9.2	12.3
50.0	31.0	8.3	11.2
48.0	29.8	7.5	10.1
46.0	28.6	7.3	9.3
44.0	27.4	6.9	9.3
42.0	26.1	6.2	8.3
40.0	24.9	5.6	7.6
38.0	23.6	5.3	7.1
36.0	22.4	4.6	6.2
34.0	21.1	4.2	5.6
32.0	19.9	3.9	5.3
30.0	18.6	3.6	4.8
28.0	17.4	3.4	4.5
26.0	16.2	3.0	4.1
24.0	14.9	2.7	3.6
22.0	13.7	2.4	3.2
20.0	12.5	2.0	2.6
18.0	11.2	1.7	2.2
16.0	9.9	1.5	2.0
14.0	8.7	1.3	1.8
12.0	7.5	1.1	1.4
10.0	6.2	.9	1.2
8.0	5.0	.7	.9
6.0	3.7	.5	.6
4.0	2.5	.3	.5
2.0	1.2	.2	.2

(b) Without regenerative braking

Vehicle speed		Road power required	
km/h	mph	kW	hp
58.0	36.0	0	0
56.0	34.8	8.8	11.8
54.0	33.6	8.3	11.2
52.0	32.3	7.8	10.4
50.0	31.0	7.0	9.4
48.0	29.8	6.7	8.9
46.0	28.6	6.3	8.4
44.0	27.4	5.8	7.8
42.0	26.1	5.3	7.1
40.0	24.9	4.7	6.4
38.0	23.6	4.5	6.0
36.0	22.4	4.2	5.6
34.0	21.1	3.7	4.9
32.0	19.9	3.3	4.4
30.0	18.6	3.2	4.3
28.0	17.4	2.9	3.9
26.0	16.2	2.5	3.3
24.0	14.9	2.3	3.1
22.0	13.7	2.0	2.7
20.0	12.5	1.7	2.3
18.0	11.2	1.6	2.1
16.0	9.9	1.4	1.8
14.0	8.7	1.2	1.6
12.0	7.5	1.0	1.3
10.0	6.2	.7	1.0
8.0	5.0	.6	.8
6.0	3.7	.4	.6
4.0	2.5	.3	.4
2.0	1.2	.1	.2

TABLE VIII. - INDICATED ENERGY CONSUMPTION

OF POWER-TRAIN VAN

Vehicle speed		Indicated energy consumption	
km/h	mph	MJ/km	kWh/mile
40.2	25.0	1.24	0.55
59.5	37.0	1.15	.51

TABLE IX. - BATTERY SPECIFICATIONS FOR POWER-TRAIN VAN

Length, m (in.)	0.26 (10 3/8)
Width, m (in.).	0.18 (7 1/16)
Height, m (in.)	0.30 (12)
Weight, kg (lbm).	33 (73)

TABLE X - BATTERY OUTPUT FOR POWER-TRAIN VAN

(a) Schedule B without regenerative braking; cycle 3; June 30, 1977

Time, s	Vehicle speed, km/h	Current, A	Voltage, V	Power, kW
0	0	0	101	0
1	4.6	211	96	20 4
2	8.8	222	93	20 7
3	12.8	209	92	19 8
4	15 1	202	92	18 6
5	17 1	223	91	20.5
6	19.6	221	91	20 8
7	21.2	150	94	14.1
8	22.8	150	93	14 0
9	23 0	150	94	14.1
10	24.5	207	91	18.9
11	25 8	204	91	18 8
12	27.4	204	91	18 7
13	28.2	146	93	13.6
14	28.6	146		13.7
15	29.2	145		13.6
16	29.8	145		13.6
17	30.4	144		13.5
18	30.8	144		13.5
19	31.5	144		13.5
20	31 7	143		13.4
21		63	97	6 1
22		66		6 4
23		69		6 7
24		114		11.1
25		115	95	11.0
26	31.6	115		11 0
27	31.7	115		11.0
28	31 8	110		10.6
29	32.1	109		10.5
30	32.1	19	98	1.8
31	31 6	18	99	1.8
32	31.3	94	99	9.3
33	31.3	94	96	9.1
34	31.3	95		
35	31.2	95		
36	31.2			
37	31.3			9.2
38	31.3			9.2
39	31 2			9.2
40	30.7	0	99	0
41	30.1		100	
42	29 6			
43	28.8			
44	26 2			
45	23.1			
46	17 6			
47	12 5			
48	4.5			

(b) Schedule B without regenerative braking, cycle 128, June 30, 1977

Time, s	Vehicle speed, km/h	Current, A	Voltage, V	Power, kW
0	0	0	92	0
1	3.5	171	84	14 4
2	7 4	237	83	19 7
3	10.7	245	79	19 5
4	13.5	232	79	18 4
5	16.2	225		17 9
6	18.1	219		17 5
7	20.3	215		17 1
8	22.1	215		17.1
9	23.7	215		17 1
10	25.0	217		17 2
11	26 3	218		17 3
12	27.5	216		17 1
13	28.6	144	83	12 1
14	29.1	143		12 0
15	29.6	143		11 9
16	30.0	142		11 9
17	30 4	141		11 8
18	30.9	140		11.7
19	31.5	140		11.7
20	31.6	86	86	7 5
21	31 6	88	87	7 6
22	31 7	89		7 8
23		90		
24		89		
25		90		
26		90		7 9
27		91	86	
28	31.6		87	
29	31 5		87	
30			87	
31			86	
32				
33				
34	31.8			
35	31.7			
36	31.5			
37	31.2	92		8.0
38	31.5	147	83	12 3
39	31 3	0	91	0
40	30 8			
41	30.5			
42	29 9			
43	28.4			
44	23.1		92	
45	16 1	1		1
46	8 7	1		.1
47	.1	1		.1

TABLE X - Continued

(c) Schedule B with regenerative braking, cycle 4; June 23, 1977

Time, s	Vehicle speed, km/h	Current, A	Voltage, V	Power, kW
0	0	0	100	0
1	3 4	33	98	3.2
2	7 6	81	95	7.8
3	10.4	84	95	8.0
4	14.1	79	↓	7 6
5	17.0	79	↓	7.5
6	20.3	80	↓	7 6
7	22.8	81	↓	7 7
8	23.7	145	94	13 6
9	24.4	194	90	17 6
10	26.1	194	90	17.4
11	27 3	194	89	17.5
12	28.1	210	↓	18.7
13	29 2	209	↓	18 7
14	30.4	209	↓	18.7
15	30 7	113	93	10.5
16	31 4	187	90	16.8
17	32.3	114	90	10.3
18	32 5	115	93	10 7
19	↓	115	↓	10.7
20	↓	115	↓	10.7
21	↓	116	↓	10 8
22	32.6	↓	↓	↓
23	↓	↓	↓	↓
24	↓	↓	↓	↓
25	↓	↓	↓	↓
26	32.7	117	↓	10.9
27	32.9	117	↓	10.9
28	32.9	105	↓	9.8
29	32.7	106	↓	9.9
30	32 7	52	94	4 9
31	32 4	53	95	5 1
32	32 0	54	95	5.2
33	31 4	54	95	5.2
34	31 3	135	92	12.5
35	31.2	↓	92	↓
36	31.4	↓	92	↓
37	31.7	↓	92	↓
38	32 0	1	98	1
39	31 4	0	↓	0
40	30 8	↓	↓	↓
41	30 1	↓	↓	↓
42	28.9	↓	↓	↓
43	26 2	↓	↓	↓
44	23 2	↓	99	↓
45	19.4	↓	↓	↓
46	15 4	↓	↓	↓
47	11 0	↓	↓	↓
48	6 2	↓	↓	↓
49	9	↓	↓	↓

(d) Schedule B with regenerative braking, cycle 125; June 23, 1977

Time, s	Vehicle speed, km/h	Current, A	Voltage, V	Power, kW
0	0	0	94	0
1	2.6	94	88	8.3
2	4.6	122	87	10.7
3	7.3	119	87	10 4
4	9.2	152	85	13.1
5	11.0	173	84	14 6
6	12 6	172	84	14 5
7	14 4	170	84	14.3
8	16 5	207	82	17 1
9	18 1	209	82	17 2
10	19.5	210	82	17 2
11	21.4	215	81	17 6
12	23.0	215	↓	↓
13	24.6	216	↓	↓
14	26.3	216	↓	↓
15	27.8	231	80	18 7
16	28.9	231	80	18.6
17	30.3	229	80	18 4
18	31.3	209	81	17.0
19	31.6	187	82	15.5
20	31.7	102	87	8.9
21	31 8	104	87	9 1
22	31.7	93	88	8 2
23	↓	95	↓	8.3
24	↓	96	↓	8.4
25	↓	↓	↓	8.4
26	↓	↓	↓	8 5
27	31.8	↓	↓	8 5
28	31.7	↓	↓	8 4
29	31.6	97	↓	8 5
30	31.7	↓	↓	8.6
31	31.6	↓	↓	8.6
32	↓	↓	↓	8.5
33	↓	↓	↓	8 6
34	↓	↓	↓	8.6
35	↓	↓	↓	8.6
36	31.5	↓	↓	8.5
37	31 5	↓	↓	8.5
38	31 4	↓	↓	8 6
39	30 8	↓	89	8.7
40	30 8	0	93	0
41	29.6	↓	↓	↓
42	26.6	↓	↓	↓
43	20 4	↓	↓	↓
44	13 4	↓	↓	↓
45	6.1	↓	↓	↓

TABLE X. - Continued.

(e) Schedule C without regenerative braking; cycle 3, July 5, 1977

Time, s	Vehicle speed, km/h	Current, A	Voltage, V	Power, kW
0	0	0	98	0
1	4.3	227	91	20.9
2	7.9	231	89	20.7
3	11 3	227	89	20.2
4	21.8	301	66	20 1
5	27.4	↓	75	22.7
6	30.7	↓	78	23.5
7	33 8	↓	79	23 9
8	36 0	↓	81	24 4
9	38.1	↓	81	24 6
10	40.3	↓	82	24 9
11	42.5	↓	83	25 1
12	44.4	296	83	24.7
13	45.1	91	84	7.6
14	45.3	194	89	17.3
15	45.8	197	89	17.5
16	46.1	198	88	17.6
17	46.9	275	84	23.4
18	47 7	271	94	25 6
19	48.0	192	89	17.1
20	48.3	164	90	14.8
21	48.4	146	90	13.2
22	48 3	66	92	6.1
23	47 9	66	94	6.2
24	47 1	103	93	9.6
25	47 8	117	92	10.9
26	46 9	136	92	12.5
27	46.8	179	89	16.0
28	46 8	191	↓	17.0
29	47 0	186	↓	16 6
30	47 3	180	↓	16 0
31	47 5	179	↓	16.0
32	47 8	172	↓	15.4
33	48 3	133	91	12 1
34	48 2	50	95	4 7
35	47.5	119	94	11 3
36	47.5	166	91	15.1
37	47 4	168	90	15 2
38	↓	170	90	15.3
39	↓	172	90	15.5
40	↓	1	96	1
41	47 0	0	97	0
42	45 8	1	↓	1
43	45 1	↓	↓	↓
44	44.3	↓	↓	↓
45	43 4	↓	↓	↓
46	42 5	↓	↓	↓
47	41 6	↓	↓	↓
48	40 8	↓	↓	↓
49	40.1	↓	↓	↓
50	39.3	0	↓	0
51	38 5	↓	98	↓
52	37.3	↓	↓	↓
53	35.1	↓	↓	↓
54	33.3	1	↓	↓
55	30.3	0	↓	0
56	28 0	1	↓	1
57	23 3	↓	↓	.1
58	18.7	↓	↓	↓
59	11.7	↓	↓	↓
60	5.0	↓	↓	↓

(f) Schedule C without regenerative braking, cycle 64; July 5, 1977

Time, s	Vehicle speed, km/h	Current, A	Voltage, V	Power, kW
0	0	0	90	0
1	3.2	267	85	22.7
2	8.3	267	75	20.3
3	12.2	264	75	19 8
4	17.6	302	54	16.4
5	22.8	↓	59	18.0
6	27.0	↓	63	19 0
7	29.3	↓	65	19 7
8	31.3	↓	66	28.1
9	33.0	↓	67	20.4
10	35.1	291	68	19 9
11	36.8	277	69	19.2
12	38.3	266	69	18.5
13	39 8	256	70	18 0
14	40 9	248	70	17 5
15	42 4	243	71	17 2
16	43 5	237	↓	16 9
17	44 6	232	↓	16.6
18	45.4	227	↓	16 3
19	46 3	222	↓	15 9
20	47 3	`219	↓	15 7
21	48 0	215	72	15.5
22	48 2	165	76	12.7
23	48 2	165	76	12 6
24	48.5	133	77	10 3
25	48 5	80	81	6 5
26	48.6	82	82	6 8
27	48 5	83	82	6.8
28	48 4	84	82	6 9
29	48.2	71	83	5 9
30	48.0	71	83	6.0
31	47.8	72	83	6 0
32	↓	153	78	12 0
33	↓	153	78	11 9
34	↓	132	78	10 3
35	47.9	109	80	8 8
36	48.0	81	82	6 7
37	48.0	62	84	5 2
38	47 9	120	84	10 1
39	47.0	150	78	11 8
40	47.7	0	87	0
41	47.1	↓	88	↓
42	46.8	↓	↓	↓
43	46 1	↓	↓	↓
44	45.6	↓	↓	↓
45	45.0	1	↓	↓
46	44.3	0	↓	↓
47	43.7	↓	↓	↓
48	42.9	↓	↓	↓
49	41.0	↓	89	↓
50	38.4	↓	↓	↓
51	33.8	1	↓	↓
52	28.4	0	↓	↓
53	23.7	1	↓	↓
54	16.2	1	↓	↓
55	9.9	1	↓	↓
56	5.7	0	↓	↓
57	.1	0	↓	↓

TABLE X. - Concluded.

(g) Schedule C with regenerative braking, cycle 4, June 29, 1977

Time, s	Vehicle speed, km/h	Current, A	Voltage, V	Power, kW
0	0	0	100	0
1	5.2	180	97	17.6
2	12.7	221	94	21.0
3	17.1	223	93	21.0
4	22.7	216	↓	20.2
5	27.1	212	↓	19.9
6	31.5	210	↓	19.6
7	34.1	208	↓	19.5
8	35.4	302	↓	28.1
9	37.4	↓	86	26.0
10	39.4	↓	87	26.3
11	41.1	↓	87	26.4
12	42.8	↓	87	26.5
13	44.0	291	88	25.6
14	45.4	282	88	24.9
15	46.8	274	88	24.3
16	47.9	268	89	23.9
17	48.5	170	95	16.2
18	48.6	192	93	18.0
19	48.8	193	93	18.0
20	49.1	193	98	18.0
21	49.3	170	94	16.0
22	49.2	113	96	10.9
23	49.1	114	↓	11.0
24	48.8	↓	↓	↓
25	48.5	↓	↓	↓
26	48.3	↓	↓	↓
27	47.9	↓	↓	↓
28	47.7	179	95	17.0
29	47.4	179	94	16.9
30	47.5	180	↓	16.9
31	47.5	181	↓	17.0
32	47.7	182	↓	17.1
33	48.2	172	↓	16.2
34	48.4	125	95	11.9
35	48.5	119	96	11.5
36	48.6	119	97	11.6
37	48.3	0	100	0
38	47.1	↓	↓	↓
39	46.1	↓	↓	↓
40	45.3	↓	↓	↓
41	44.4	↓	↓	↓
42	43.9	↓	↓	↓
43	43.3	↓	↓	↓
44	42.5	↓	↓	↓
45	41.8	↓	↓	↓
46	39.5	↓	↓	↓
47	36.1	↓	↓	↓
48	31.5	↓	↓	↓
49	25.6	↓	↓	↓
50	17.4	↓	↓	↓
51	11.6	↓	↓	↓
52	5.1	↓	↓	↓
53	.2	↓	↓	↓

(h) Schedule C with regenerative braking; cycle 84, June 29, 1977

Time, s	Vehicle speed, km/h	Current, A	Voltage, V	Power, kW
0	0	0	92	0
1	6.0	268	75	20.2
2	13.3	267	73	19.7
3	18.7	266	72	19.3
4	24.0	267	72	19.3
5	29.3	303	65	19.9
6	33.0	303	67	20.4
7	37.1	264	68	18.1
8	39.1	246	↓	16.8
9	40.1	236	↓	16.2
10	41.0	231	↓	15.8
11	41.7	226	↓	15.4
12	42.3	222	↓	15.1
13	42.9	222	↓	14.9
14	43.7	214	↓	14.6
15	44.3	210	↓	14.4
16	44.9	207	↓	14.2
17	45.6	204	↓	14.0
18	46.2	202	↓	13.9
19	46.4	200	↓	13.7
20	47.1	197	↓	13.5
21	47.6	195	↓	13.4
22	47.9	193	76	14.3
23	48.2	163	73	11.9
24	48.3	152	72	11.1
25	48.4	151	73	11.0
26	48.4	139	73	10.3
27	48.5	137	75	10.3
28	48.5	125	75	9.4
29	48.4	125	79	9.9
30	48.4	71	76	5.4
31	48.5	123	76	9.4
32	48.4	140	74	10.4
33	↓	141	76	10.7
34	↓	112	↓	8.6
35	↓	113	↓	8.6
36	↓	114	↓	8.7
37	↓	121	74	8.9
38	48.3	141	74	10.4
39	48.4	140	86	12.1
40	48.2	0	88	0
41	47.7	↓	89	↓
42	47.1	↓	↓	↓
43	36.3	↓	↓	↓
44	45.6	↓	↓	↓
45	44.9	↓	↓	↓
46	44.2	↓	90	↓
47	43.2	↓	↓	↓
48	42.7	↓	↓	↓
49	42.0	↓	↓	↓
50	39.1	↓	↓	↓
51	36.1	↓	↓	↓
52	32.6	↓	↓	↓
53	28.9	↓	↓	↓
54	25.6	↓	↓	↓
55	21.1	↓	91	↓
56	15.6	↓	↓	↓
57	10.8	↓	↓	↓
58	4.0	↓	↓	↓
59	.2	↓	↓	↓

TABLE XI. - BATTERY OUTPUT FOR POWER-TRAIN VAN DURING ACCELERATION

[Test date, July 21, 1977]

(a) At full battery charge

Time, s	Gradeability, percent	Current, A	Voltage, V	Power, kW
21	0	216	87	19.0
20	2.1	219	85	18.8
19	2.6	223	↓	19.1
18	2.7	226	↓	19.4
17	3.0	231	↓	19.8
16	3.0	236	↓	20.1
15	3.3	241	84	20.5
14	3.6	248	↓	21.0
13	3.9	254	↓	21.5
12	4.4	263	↓	22.2
11	5.1	273	83	22.9
10	5.8	286	83	23.7
9	6.4	302	82	24.9
8	7.3	321	81	26.2
7	8.6	349	80	28.2
6	10.1	388	79	30.8
5	13.0	445	76	34.2
4	18.1	512	72	37.3
3	26.6	304	69	21.2
2	12.8	215	87	18.8
1	15.0	201	90	18.1

(b) At 40-percent battery discharge

Time, s	Gradeability, percent	Current, A	Voltage, V	Power, kW
25	0	215	84	18.0
24	7	217	84	18.1
23	1.4	220	83	18.3
22	2.2	223	↓	18.5
21	2.4	226	↓	18.8
20	2.3	229	↓	19.0
19	2.6	232	↓	19.5
18	2.5	236	↓	19.5
17	2.8	241	↓	19.9
16	3.1	246	↓	20.3
15	3.5	253	82	20.3
14	4.0	259	82	21.2
13	4.1	267	82	21.7
12	4.4	275	81	22.4
11	4.8	287	81	23.1
10	5.5	300	80	24.0
9	6.0	315	80	25.1
8	6.8	340	79	26.7
7	8.1	368	78	28.5
6	9.7	411	76	31.2
5	12.7	480	74	35.4
4	15.9	597	70	41.8
3	25.5	390	62	24.4
2	14.1	242	86	20.8
1	14.2	226	87	19.6

(c) At 80-percent battery discharge

Time, s	Gradeability, percent	Current, A	Voltage, V	Power, kW
32	0	196	79	15.4
31	3	198	79	15.5
30	6	199	79	15.6
29	9	200	78	15.7
28	1.2	202	↓	15.8
27	1.5	204	↓	15.9
26	1.3	206	↓	16.1
25	1.5	208	↓	16.3
24	1.7	211	↓	16.4
23	1.9	213	↓	16.6
22	2.0	216	↓	16.8
21	2.2	219	↓	17.0
20	2.4	222	77	17.2
19	2.7	226	↓	17.5
18	2.8	230	↓	17.8
17	2.8	235	↓	18.0
16	3.0	240	↓	18.4
15	3.2	246	76	18.8
14	3.5	253	↓	19.3
13	3.9	261	↓	19.8
12	4.3	270	↓	20.3
11	4.7	281	75	21.0
10	5.3	294	74	21.8
9	6.1	312	73	22.8
8	6.7	332	72	24.1
7	7.5	361	71	25.7
6	9.4	401	69	27.8
5	11.6	466	67	31.2
4	14.4	572	63	35.8
3	21.1	248	57	14.6
2	12.9	253	79	20.1
1	14.1	250	80	19.9

TABLE XII. - PERFORMANCE CHARACTERISTICS OF PROTOTYPE MOTOR OF SAME

MODEL AS USED IN POWER-TRAIN VAN

Voltage, V	Current, A	Torque		Speed, rpm	Power		Efficiency, percent
		N-m	lbf-ft		kW	hp	
[a]96	150	26.7	19.7	4710	13.3	17.9	0.91
	175	35.9	26.5	4100	15.4	20.6	.91
	200	46.0	33.9	3720	17.9	24.0	.93
	225	57.0	42.0	3390	20.2	27.1	.94
	250	70.2	51.8	3060	22.5	30.2	.94
	275	83.3	61.4	2820	24.7	33.1	.93
	300	95.7	70.6	2660	26.6	35.7	.93
[b]48	100	12.7	9.4	2825	3.8	5.1	0.78
	150	28.3	20.9	1950	5.8	7.8	.81
	200	47.9	35.3	1520	7.7	10.3	.80
	250	72.5	53.5	1240	9.4	12.7	.79
	300	100.2	73.9	1040	10.9	14.6	.76

[a]Tests were conducted on production dynamometer. Power was supplied to motor from three-phase, full-wave rectifier bridge.

[b]Tests were conducted on a different dynamometer than the 96-V tests. Power was supplied to the motor from a motor-generator set that had negligible ripple.

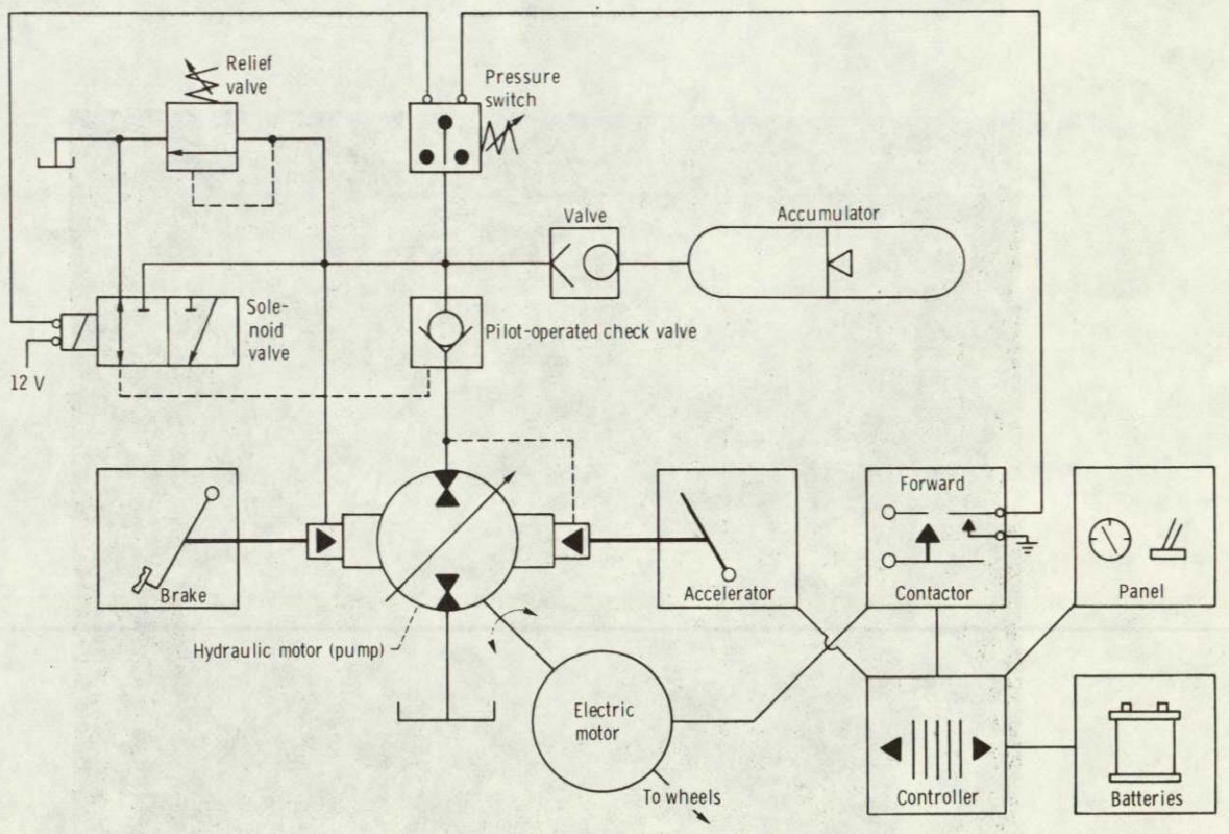


Figure 1. - Schematic diagram of hydraulic regenerative braking system used in Power-Train Van.

Figure 2. - Power-Train experimental electric delivery van.

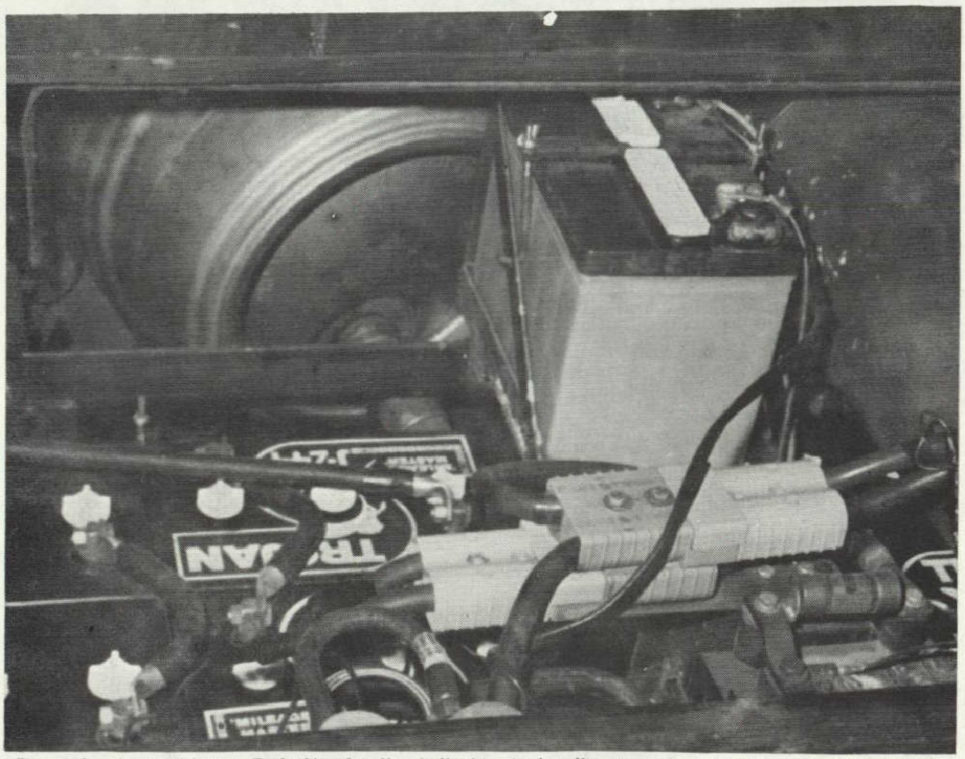


Figure 3. - View of Power-Train Van traction batteries, hydraulic reservoir, and accessory battery, taken through access door under cargo area.

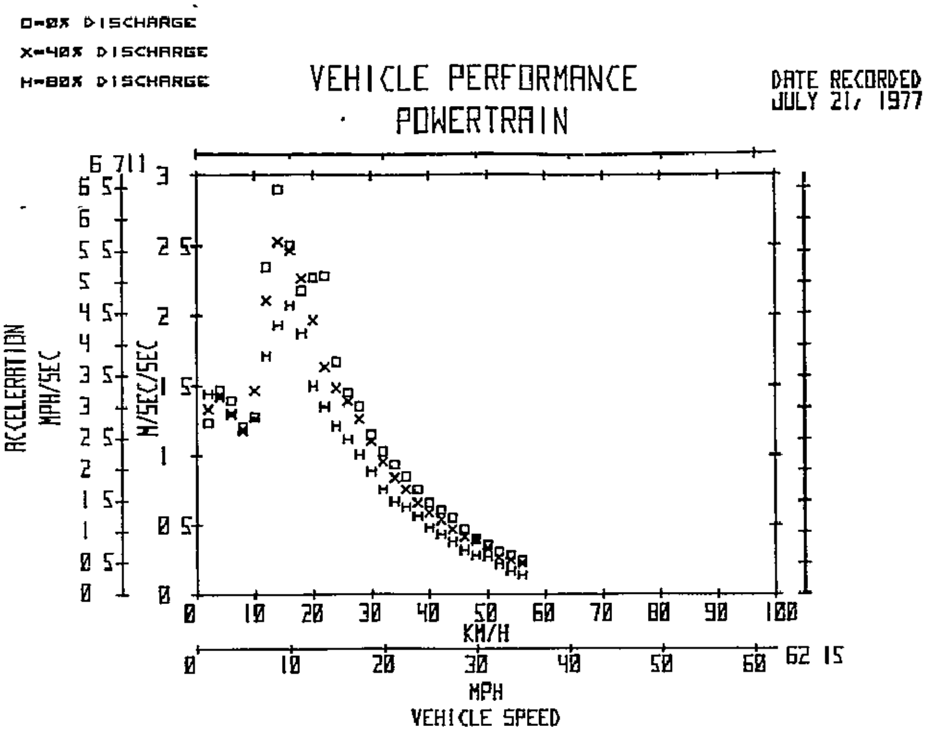


Figure 6. - Acceleration as a function of speed without regenerative braking.

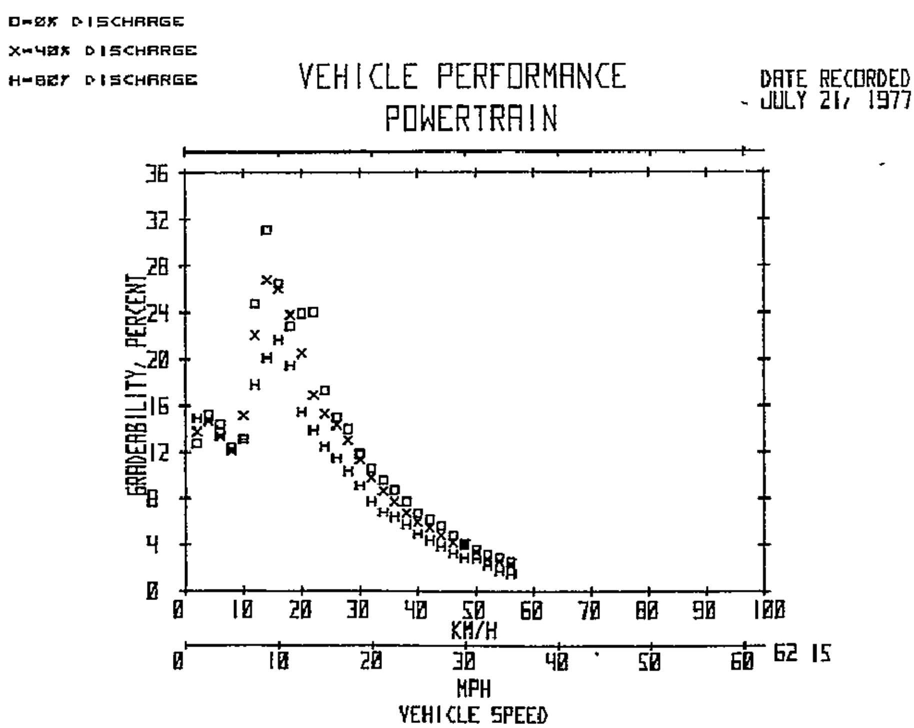
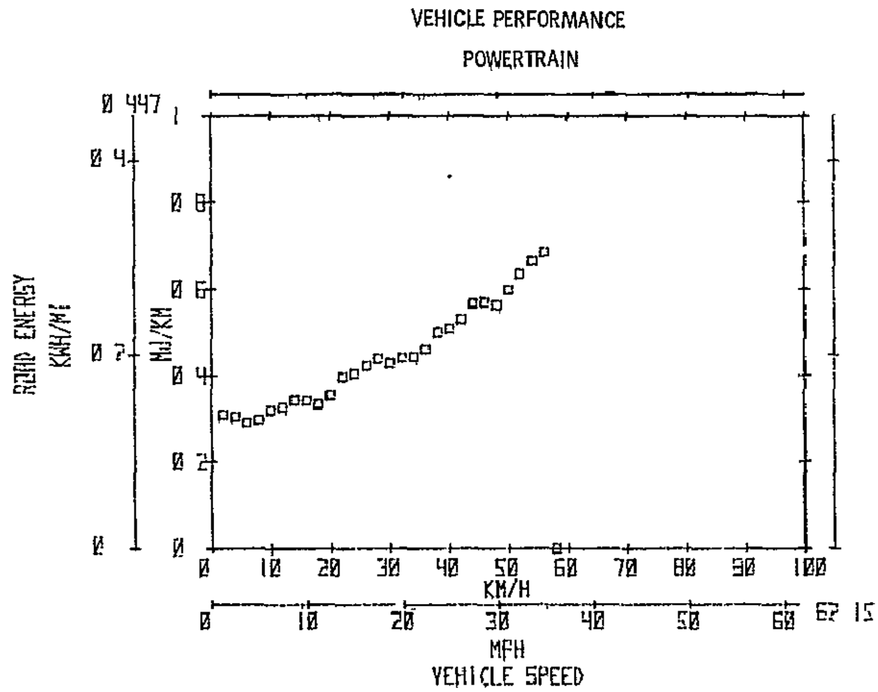
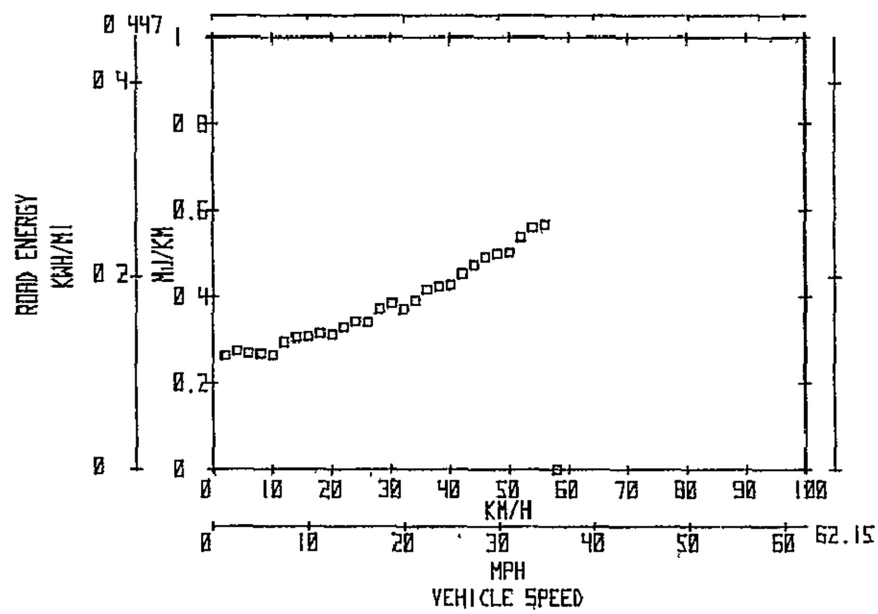


Figure 7 - Gradeability as a function of speed without regenerative braking.



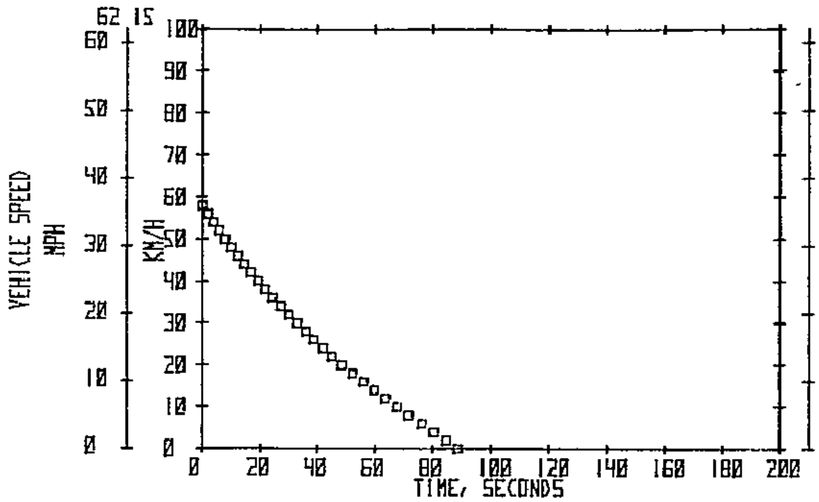
(a) With regenerative braking, July 20, 1977.



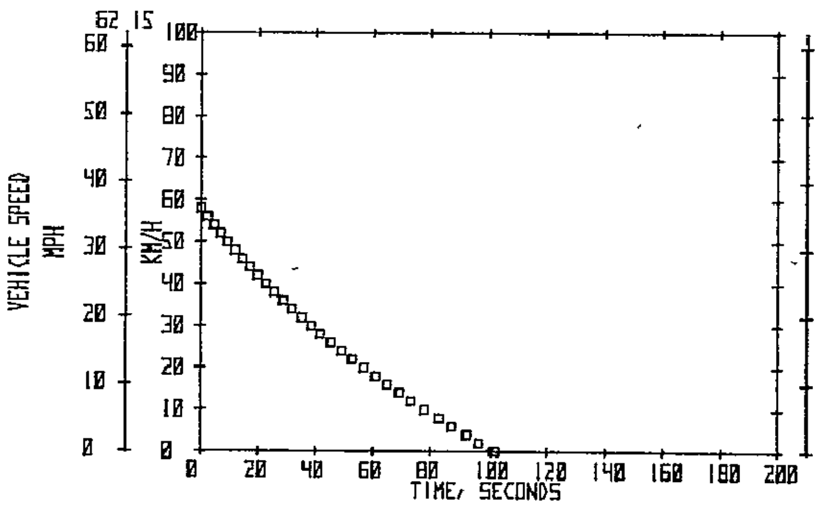
(b) Without regenerative braking, July 21, 1977.

Figure 8 - Road energy as a function of speed.

VEHICLE PERFORMANCE
POWERTRAIN

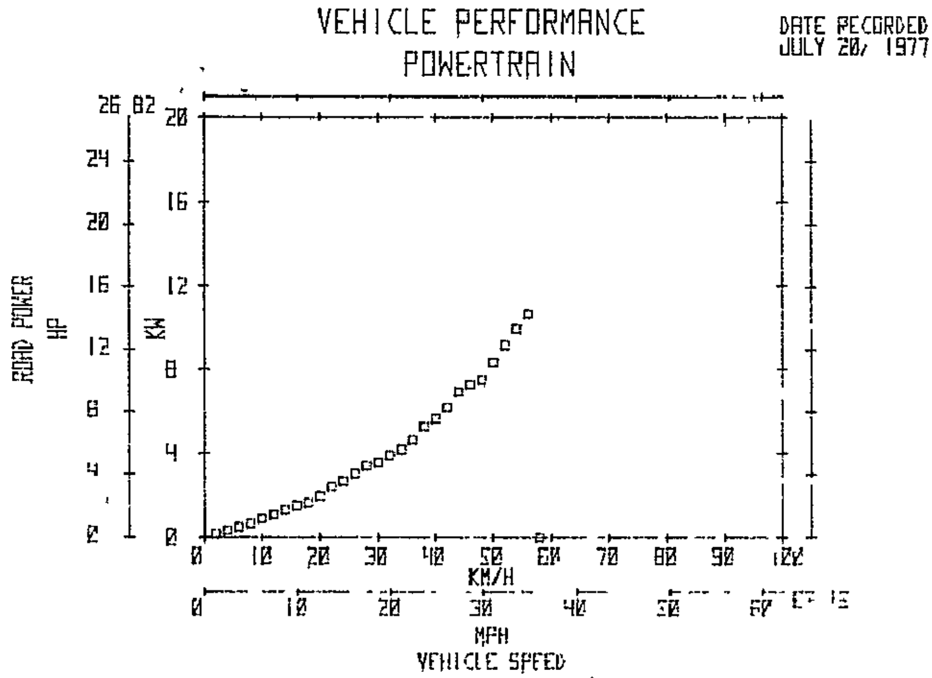


(a) With regenerative braking, July 20, 1977

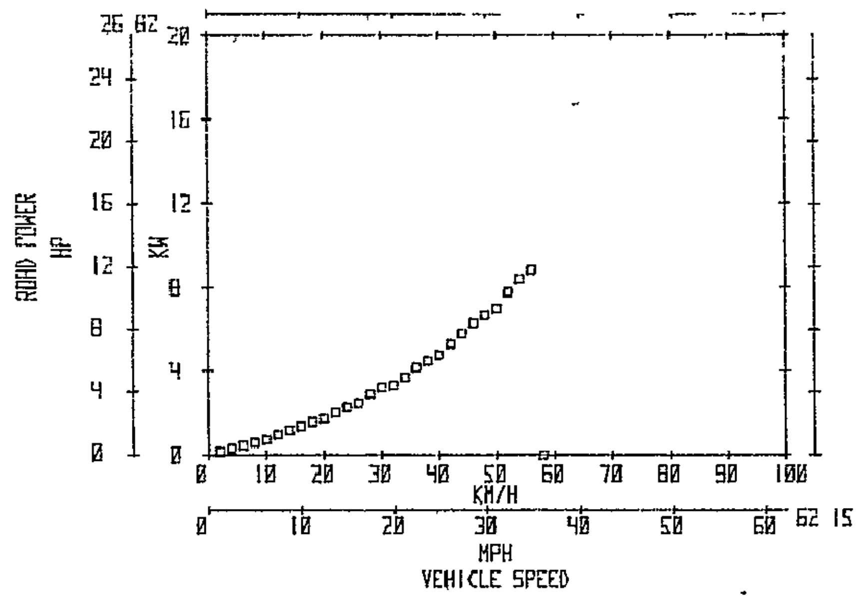


(b) Without regenerative braking, July 21, 1977.

Figure 9. - Vehicle deceleration.



(a) With regenerative braking, July 20, 1977.



(b) Without regenerative braking; July 21, 1977.

Figure 10 - Road power as a function of speed.

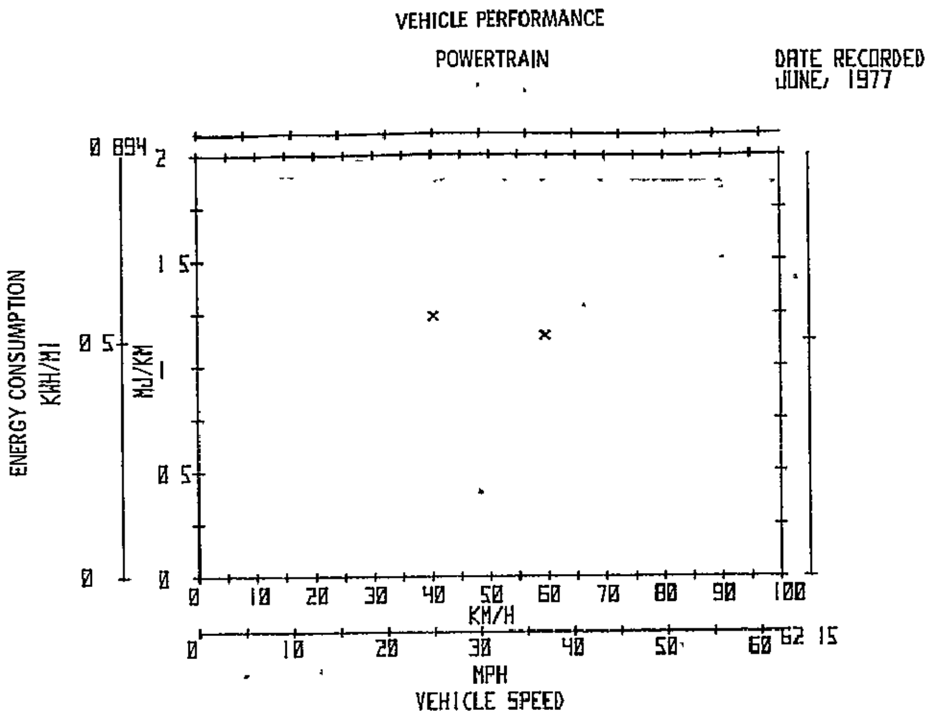


Figure 11 - Indicated energy consumption as a function of speed.

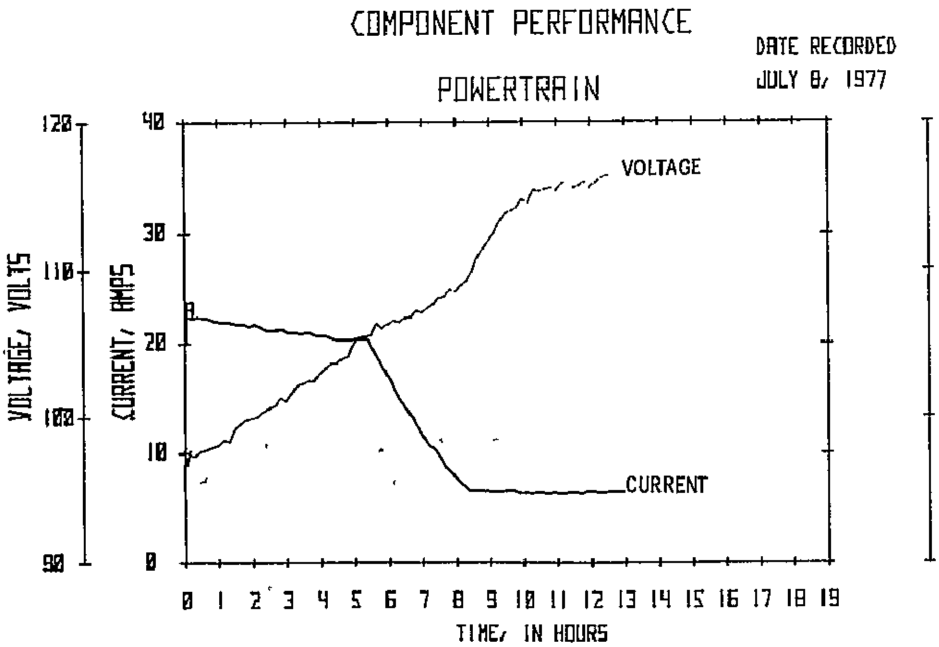


Figure 12 - Battery charger output voltage and current

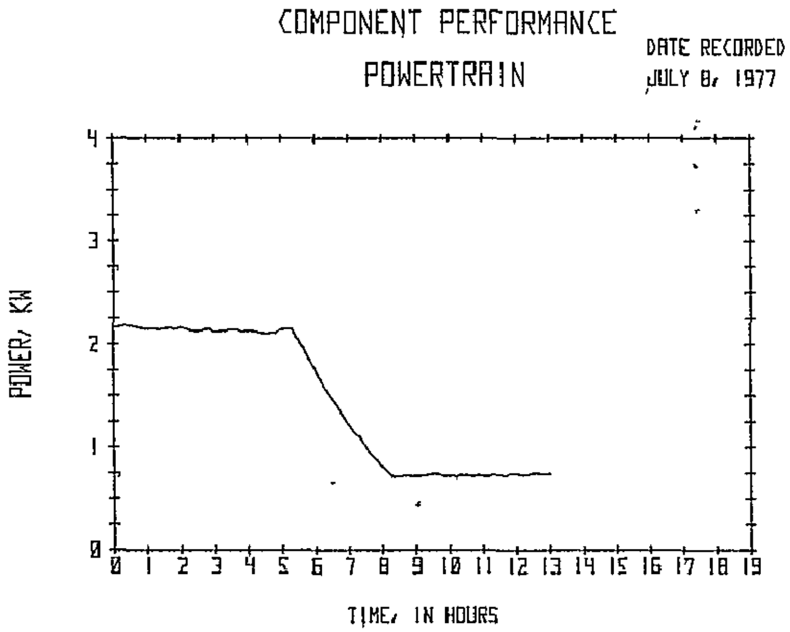


Figure 13 - Battery charger output power.

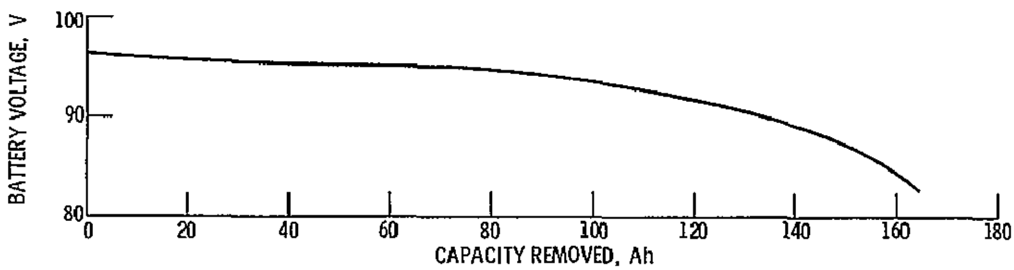


Figure 14, - Battery capacity of Power-Train Van at 75-ampere discharge rate

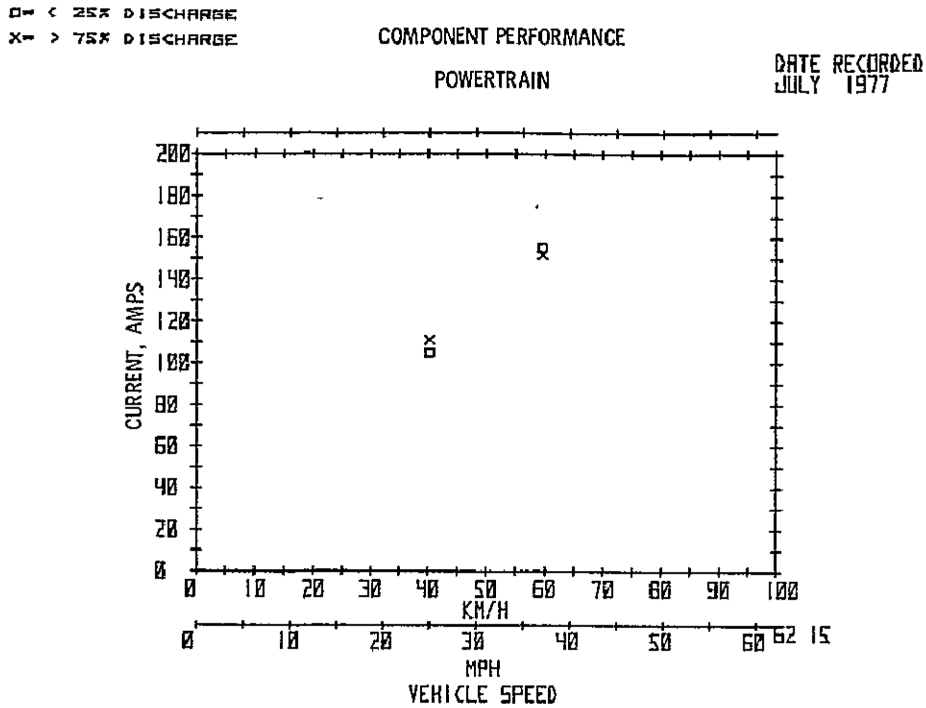


Figure 15. - Current as a function of speed

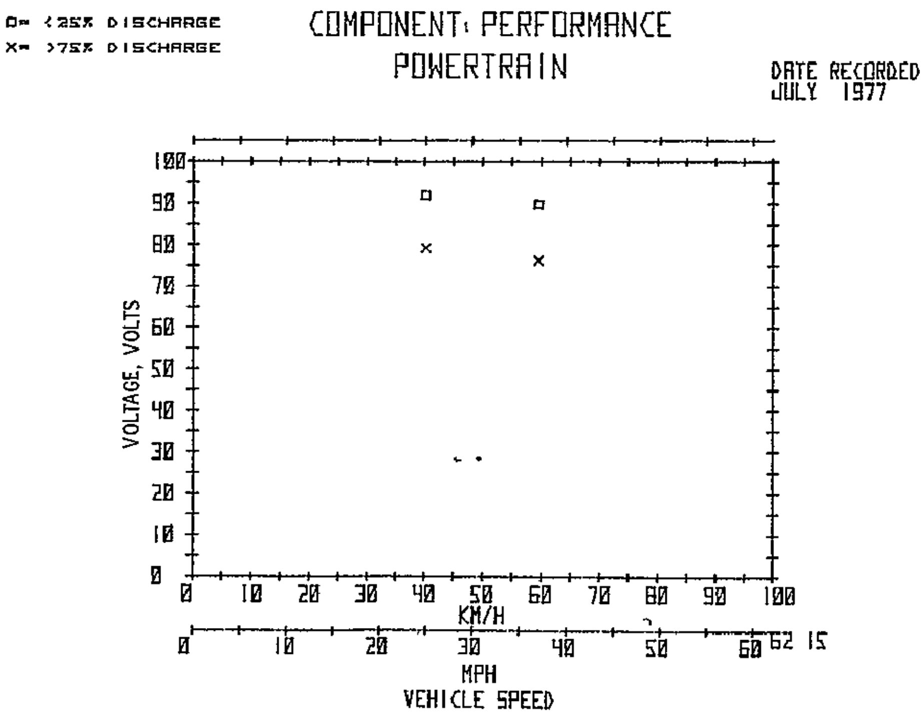


Figure 16 - Voltage as a function of speed

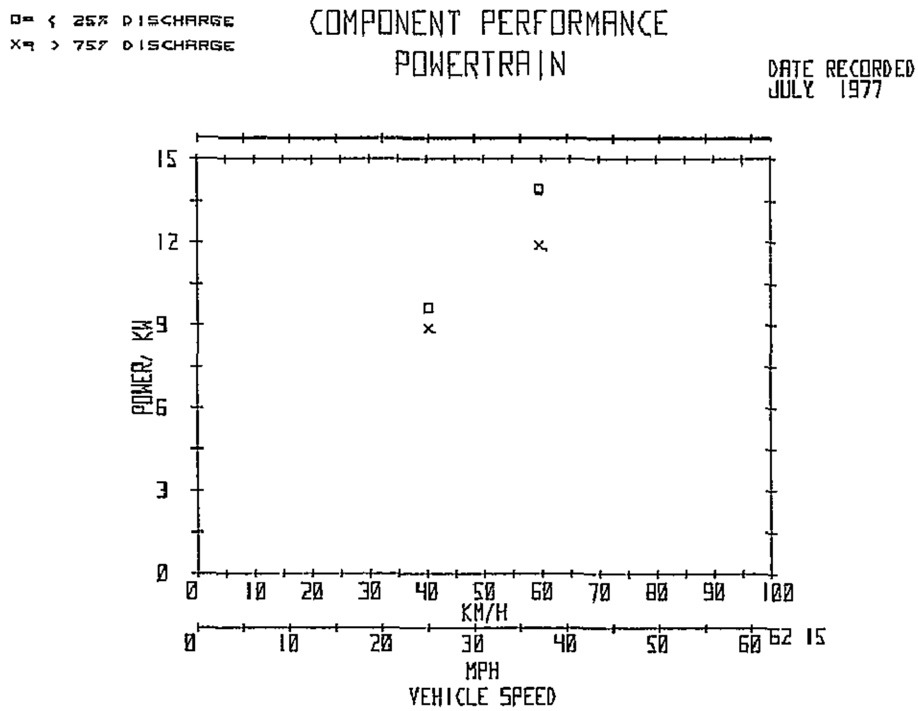
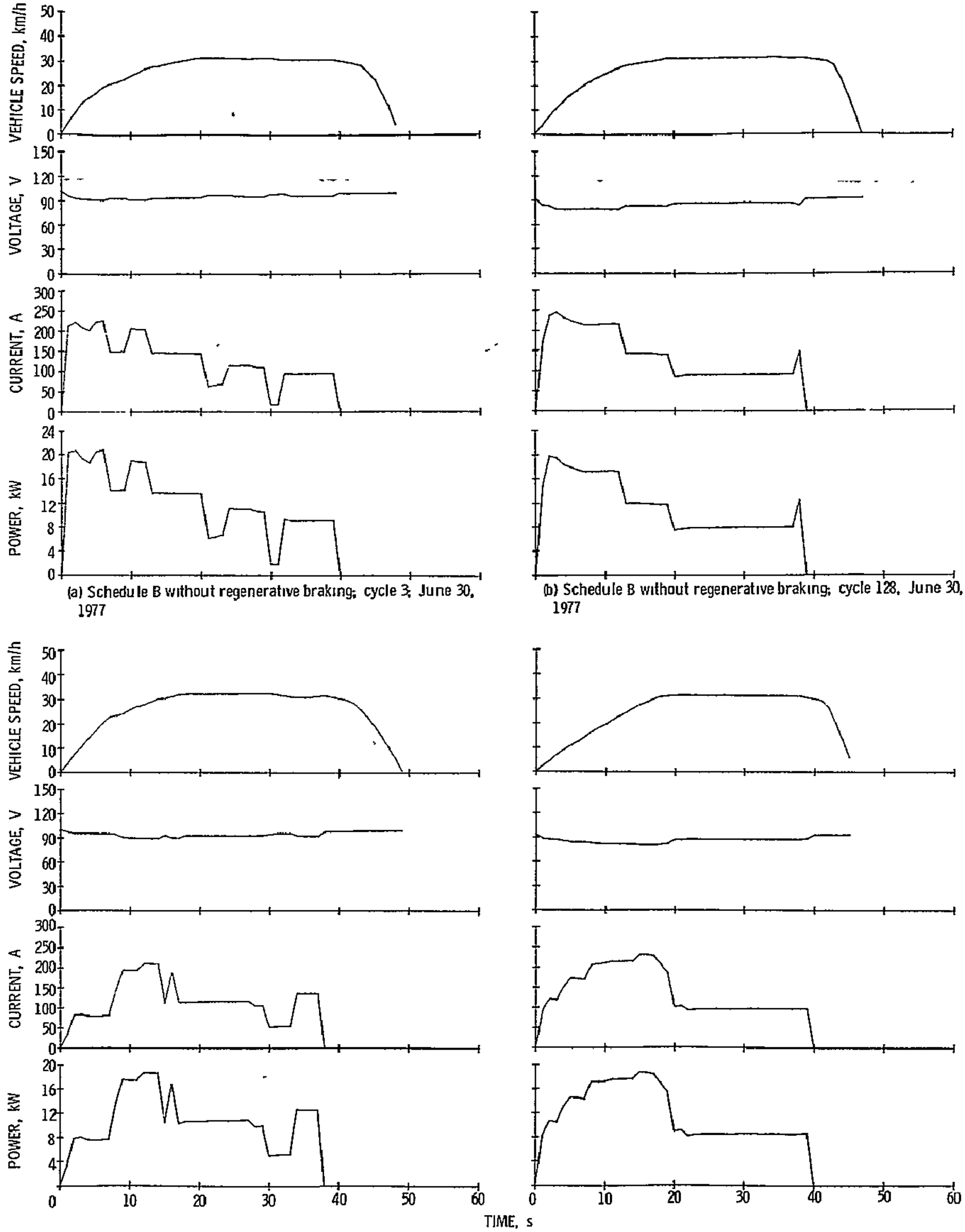


Figure 17 - Power as a function of speed.



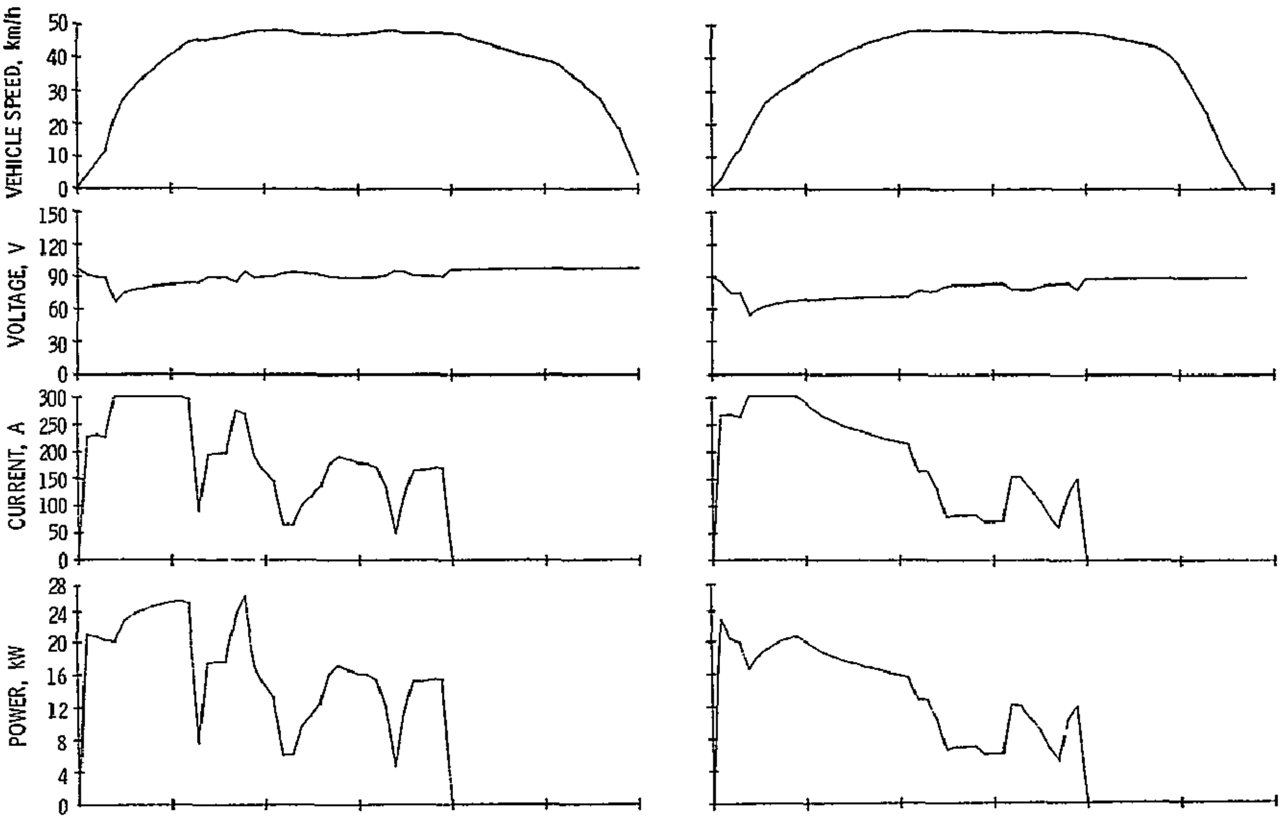
(a) Schedule B without regenerative braking; cycle 3; June 30, 1977

(b) Schedule B without regenerative braking; cycle 128, June 30, 1977

(c) Schedule B with regenerative braking, cycle 4, June 23, 1977.

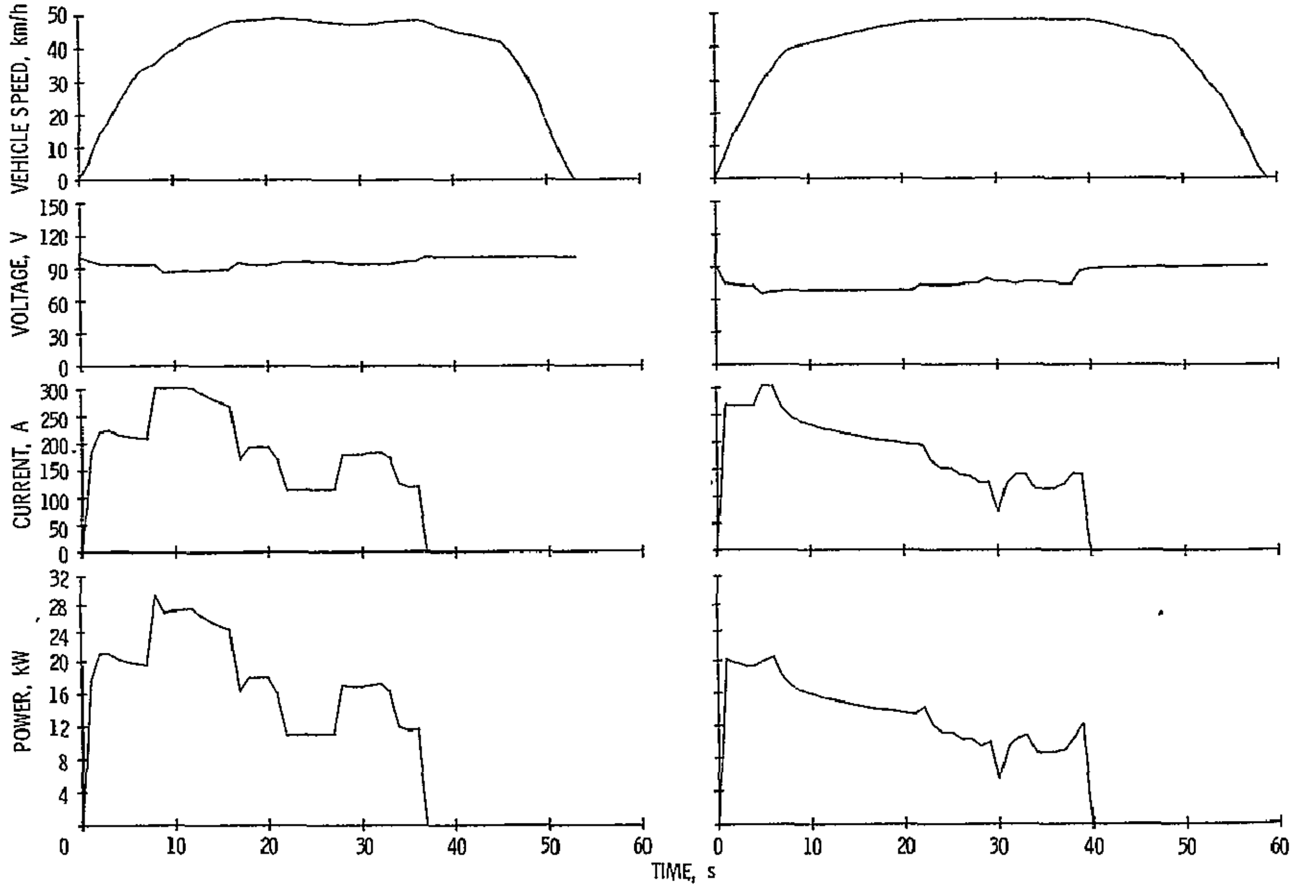
(d) Schedule B with regenerative braking, cycle 125; June 23, 1977

Figure 18 - Battery output as a function of time



(e) Schedule C without regenerative braking, cycle 3; July 5, 1977

(f) Schedule C without regenerative braking; cycle 64, July 5, 1977.



(g) Schedule C with regenerative braking, cycle 4, June 29, 1977

(h) Schedule C with regenerative braking, cycle 84; June 29, 1977.

Figure 18. - Concluded

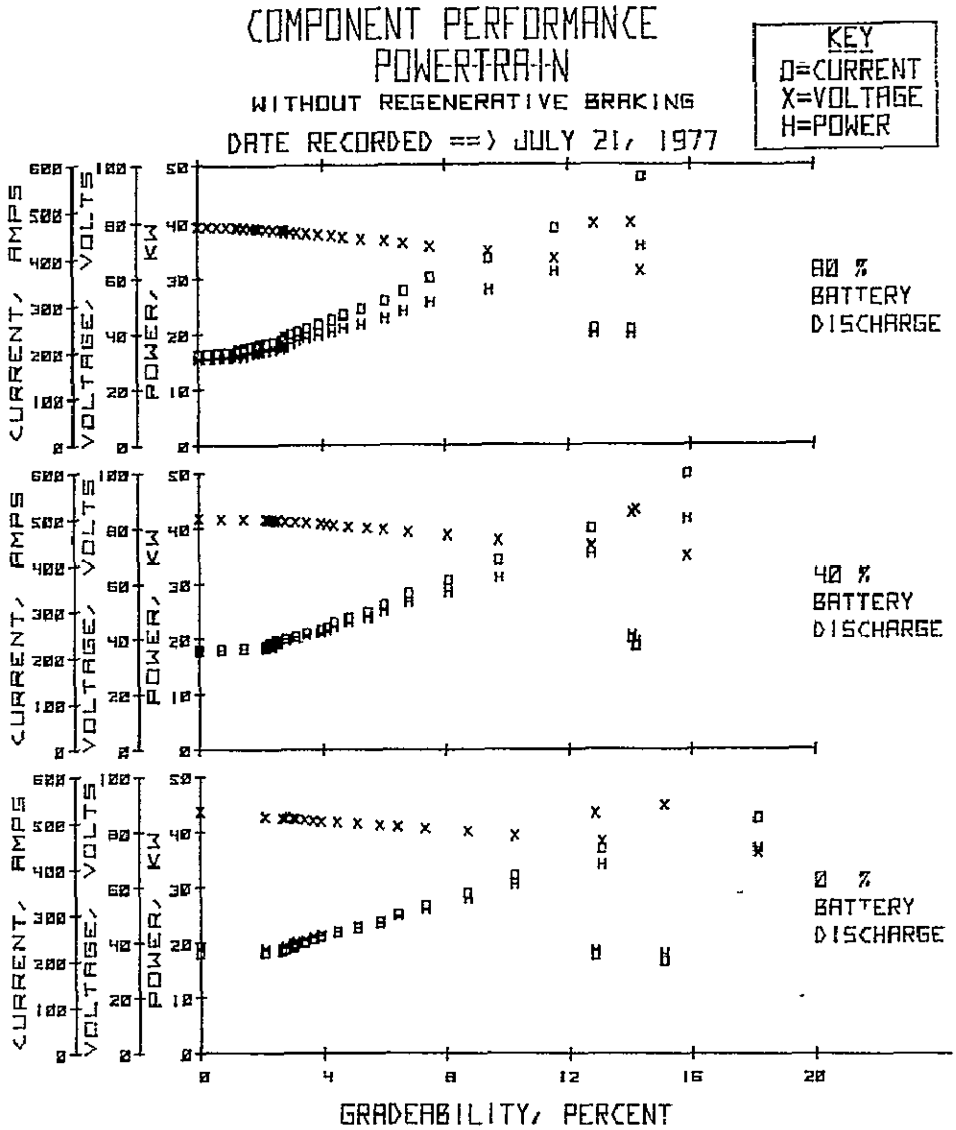


Figure 19. - Battery output during acceleration

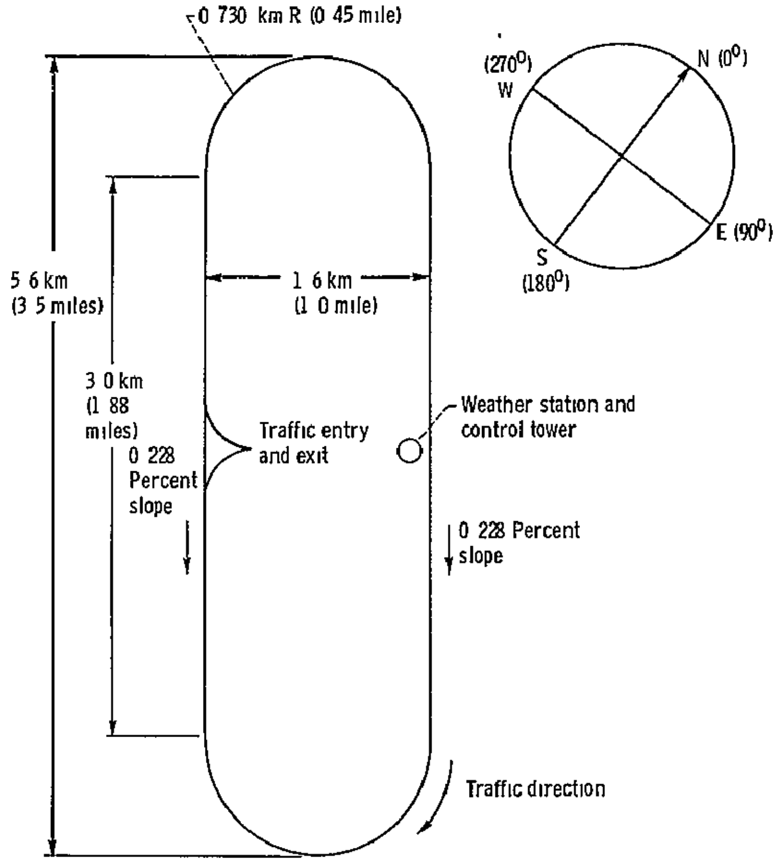


Figure B-1 - Characteristics of Transportation Research Center Test Track, East Liberty, Ohio

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 C-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

Figure C-2. - Test checklists

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 C-2. - Concluded

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 C-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, ^{o}F	____	____	____
Wind speed, mph	____	____	____
Wind direction	____	____	____
Pressure, in Hg	____	____	____

Battery temperature, ^{o}F Before ________ After ________
Motor temperature, ^{o}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, ^{o}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 C-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 C-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 C-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 ______

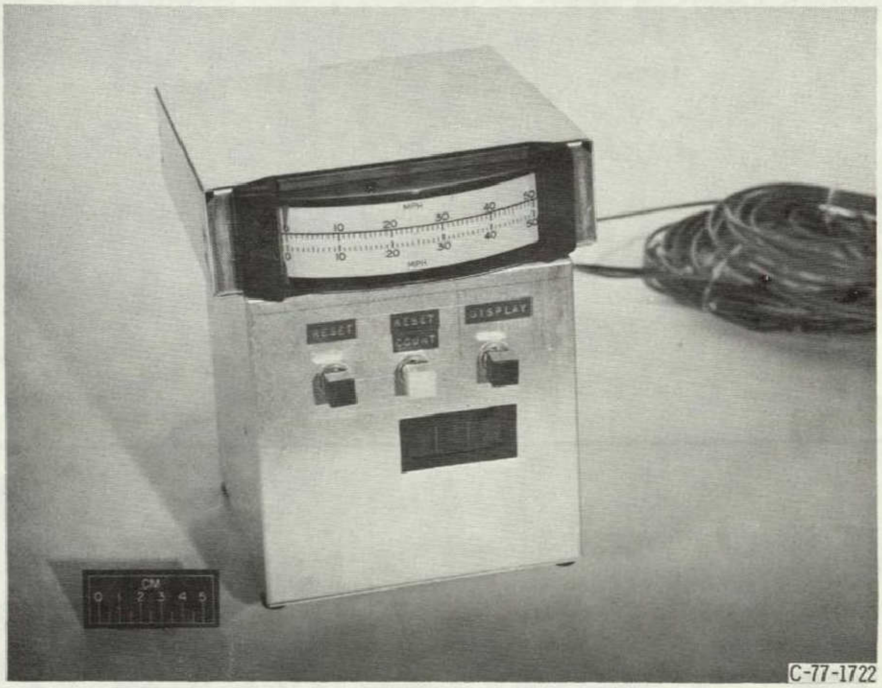
Power in, kWh ______

Energy consumption, kWh/mile ______

Was planned driving cycle followed? ______

General comments ______

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



C-77-1722

Figure C-8. - Cycle timer.

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