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BASELINE TESTS OF THE VOLKSWAGEN TRANSPORTER 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 VOLKSWAGEN TRANSPORTER

ELECTRIC DELIVERY VAN

Richard F. Soltis, Edward McBrien, John M. Bozek,
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SUMMARY

The Volkswagen Transporter, an electric delivery van manufactured by Volkswagen Werk AG of West Germany, was tested at the Transportation Research Center Test Track in East Liberty, Ohio, between May 10 and June 23, 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 Volkswagen vehicle performance test results are presented in this report.

The Volkswagen Transporter is a standard Volkswagen van that has been converted to an electric vehicle. It is powered by a 144-volt traction battery. A direct-current (DC) chopper controller, actuated by a conventional accelerator pedal, regulates the voltage or power applied to the 16-kilowatt (21-hp) motor. The braking system uses conventional hydraulic braking in combination with an electric regenerative braking system.

All tests were run at the gross vehicle weight of 3075 kilograms (6780 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		Energy consumption	
km/h	mph	km	mile		MJ/km	kWh/mile	MJ/km	kWh/mile
40	25	117.5	73.0	7.5	0.67	0.30	1.23	0.55
56	35	87.0	54.1	11.5	.74	.33	1.45	.65
69	43	63.2	39.2	15.0	.80	36	1.66	.74
B[a]		71.5	44.5	----	----	----	2.12	.94
B[b]		67.8	42.1	----	----	----	2.00	.90
C[a]		47.5	29.5	----	----	----	2.33	1.04
C[b]		47.2	29.3	----	----	----	2.33	1.04

[a]With regenerative braking.

[b]Without regenerative braking.

The Volkswagen Transporter 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 14 seconds. The gradeability limit was 14 percent.

Measurements were made to assess the performance of the vehicle components. The performance was as follows:

Charger efficiency over a complete charge cycle, percent	78 to 87
Battery efficiency with 10 percent overcharge, percent	77

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 Jens-Peter Altendorf of Volkswagen Werk AG and Peter Breuer of Siemens AG in conducting these tests 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.

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 the 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, battery characteristics, controller efficiency, and motor efficiency of the Volkswagen Transporter electric delivery van.

TEST VEHICLE DESCRIPTION

The Volkswagen Transporter is a German-built electric delivery van that can carry three passengers and a payload of 800 kilograms (1763 lbm). The vehicle is shown in figure 1 and described in appendix A. The vehicle is powered by a separately excited, shunt-wound DC motor that was specially developed by Siemens AG of West Germany. A DC chopper controller is used to control power to the electric motor. The motor is bolted directly to the transaxle of the vehicle, eliminating the need for a clutch. A forward-or-reverse switch to control the direction of the vehicle is located on the dashboard. The lead-acid traction battery is made up of 24 VARTA 6-volt modules connected in series to form a 144-volt battery. This battery is located under the cargo area. It is removed by opening the side door on the passenger side of the vehicle and sliding the battery pack out with a special manually operated fixture (fig. 2). In addition to standard hydraulic brakes, the vehicle is equipped with an electric regenerative braking system, which may be disconnected by a switch on the dashboard. When the brake pedal is depressed, the regenerative braking is initiated first, followed by the hydraulic braking. Regenerative braking is effective down to zero speed. An off-board charger manufactured by VARTA Batterie AG charges the traction battery. It is controlled by an external timer. The charger is a 380-volt, three-phase, 50-hertz alternating-current (AC) charger. It fully recharges the vehicle batteries in approximately 12 hours. A separate 12-volt battery powers the vehicle's auxiliary electrical system and the regulator's electronics. This battery is continuously charged by the 144-volt battery with a 144-volt to 12-volt DC-to-DC converter.

INSTRUMENTATION

Measurements taken during the performance testing of the Volkswagen Transporter included vehicle speed, vehicle distance, battery voltage, battery current, and ampere-hours from the traction battery. Battery voltage and current were recorded on one strip-chart recorder; vehicle speed and distance were recorded on another. The recorders were two-channel Honeywell Electronik 195 recorders. The battery current was measured with a 250-ampere, 60-millivolt shunt (fig. 3). This same shunt was also used to measure the integrated battery current for the battery pack. An on-board current integrator, Curtiss Model SHR-C3, was used for this measurement. Its output was recorded manually after each test.

The strip-chart recorders and the integrator were operated from a Tripp Lite DC-to-AC power inverter. The inverter was powered by a separate 12-volt battery that was fully charged before each test.

A Nucleus Corporation Model NC-7 precision speedometer (fifth wheel) was used to measure the 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 assembly was calibrated for every constant-speed range test by using an electronic pulse generator to simulate rotation of the fifth wheel. The accuracy of the distance and velocity readings were within ±1.0 percent of the readings.

The strip-chart recorders and current integrators were calibrated every two or three days. For these calibrations, a Hewlett-Packard Model 6920B meter calibrator was used. This meter has an accuracy of 0.2 percent of reading and a usable voltage range of 0.01 to 1000 volts.

After the overall performance testing of the Volkswagen Transporter was completed, the strip-chart recorders were removed and a 14-channel, frequency-modulated (FM) magnetic tape recorder was installed within the vehicle in order to obtain additional component data. These tests and the data and results obtained will be described in a later report.

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 were measured on a Honeywell strip-chart recorder. The current measurement used a 500-ampere-per-100-millivolt current shunt. Power into the charger was initially measured by an Ohio Semitronics, Inc., Model WM-365A wattmeter. When an industrial kilowatt-hour meter (for 380 V) was obtained, it was substituted for the wattmeter. The kilowatt-hour meter was a General Electric high-voltage V-65-S meter that was capable of handling 480-volt, 60-cycle, three-phase current.

For the charger efficiency tests the Model WM-365A wattmeter was used in conjunction with Hall-effect current sensors manufactured by Ohio Semitronics, Inc.

TEST PROCEDURES

The tests described in this report were conducted at the Transportation Research Center Test Track, a three-lane, 12-kilometer (7.5-mile) track located in East Liberty, Ohio. A 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 determine the vehicle's maximum speed (appendix C). 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, 3075 kilograms (6780 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 69 kilometers per hour (43 mph) for the Volkswagen Transporter.

Range tests were run at constant speeds of 40, 56, and 69 kilometers per hour (25, 35, and 43 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 all speeds.

Range Tests under Driving Schedules

Both the 32-kilometer-per-hour (20-mph) schedule B stop-and-go driving cycle and the 48-kilometer-per-hour (30-mph) schedule C stop-and-go driving cycle, shown in figure 4, were run with this vehicle. 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 vehicle was unable to accelerate rapidly enough to reach the test speed in the prescribed time.

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. Depth of discharge was determined from the number of ampere-hours removed from the batteries. Coast-down data were taken with the drive switch in neutral after the acceleration tests and with fully charged batteries in order to start the coast-down runs 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 was determined from tractive force tests by towing a second vehicle. The driver of the towed vehicle, by applying the footbrake, maintained a speed of about 3 kilometers per hour (2 mph) while the test vehicle was being driven with a wide-open throttle. The force was measured by a 13 000-newton (3000-lbf) load cell attached to the tow chain between the vehicles. The test was run with the batteries fully charged and 40 and 80 percent discharged.

Charger Efficiency Tests

Two methods were used to determine charger efficiency as a function of charge time. In the first method the GE V-65-S industrial 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. Industrial 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 6 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, the energy into the charger, and the instrument used in its measurement. These data were used to determine vehicle range, battery efficiency, and energy consumption.

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 74 kilometers per hour (46 mph) for this vehicle. This differs from the maximum speed used in the range tests.

Four constant-speed range tests were run at 40 kilometers per hour (25 mph), two at 56 kilometers per hour (35 mph), and three at 69 kilometers per hour (43 mph). In addition, four schedule B range tests and four schedule C range tests were run, two each with regenerative braking and two each without regenerative braking. These test results are shown in table I. The constant-speed range test results are plotted in figure 5. Most of the range test results were within ±5 percent of the mean.

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 is shown in figure 6 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

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

Maximum acceleration as a function of speed is shown in figure 7 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

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

in SI units

or

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

in U.S. customary units

where $\bar{a}_n$ is average acceleration in meters per second squared (mph/sec). The maximum grade the Volkswagen Transporter can negotiate as a function of speed is shown in figure 8 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 was determined by measuring the tractive force with a load cell while towing a second vehicle at about 3 kilometers per hour (2 mph). It was 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 Volkswagen Transporter was capable of exerting the following tractive forces for three states of battery discharge:

(1) Fully charged, 4270 newtons (960 lbf)

(2) 40 Percent discharged, 3870 newtons (870 lbf)

(3) 80 Percent discharged, 3470 newtons (780 lbf)

At a vehicle weight of 3075 kilograms (6780 lbm) the resulting gradeability limits were

(1) Fully charged, 14.3 percent

(2) 40 Percent discharged, 12.9 percent

(3) 80 Percent discharged, 11.6 percent

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.

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

Vehicle coast-down tests were conducted both with and without the drive train (differential, transmission, and electric motor) connected to the wheels. In normal operation the electric motor cannot be declutched (disconnected) from the wheels. It was mechanically disconnected by disconnecting the drive shafts between the wheels and the differential. The drive shafts were wired in place so they did not drag.

With the drive shafts connected, the vehicle was self-powered. When they were disconnected, it was necessary to tow the vehicle to speed before starting the coast-down tests.

The coast-down data used to calculate road energy were averaged and plotted as vehicle deceleration versus vehicle speed in figure 9(a) with the drive shafts connected and in figure 9(b) with them disconnected. Coast-down time increases significantly when the drive train is disconnected from the wheels.

The results of the road energy calculations are shown in figure 10(a) and table V(a) for the vehicle with the drive train connected and in figure 10(a) and table V(b) with it disconnected.

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 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:

$$P_n = 3.86\times10^{-5} W \frac{V_{n-1}^2 - V_n^2}{t_n - t_{n-1}}, \text{ kW}$$

or

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

The results of road power calculations are shown in figure 11(a) and table VI(a) with the drive train connected to the wheels and in figure 11(b) and table VI(b) with it disconnected. Both road energy and road power are significantly lower when the drive train is disconnected.

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.

Initially, the indicated energy consumption was measured by using a wattmeter and integrating over the charge time. Then, when the high-voltage, three-phase kilowatt-hour meter became available, it was used to measure the energy input to the battery charger after each range test. The results derived from both methods on the same tests were all within 3 percent. Some overcharge of the battery 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 12 for the constant-speed tests and in table VII for the constant-speed and driving cycle 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 which, at ERDA's direction, 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 22.5 meters (74 ft) to 26.5 meters (87 ft). Six stops were also made from 69 kilometers per hour (43 mph), again three from each direction. Stopping distances varied from 39.6 meters (130 ft) to 45.1 meters (148 ft).

Stops on a curve. - Three stops were made going into a 0.3-g curve from 69 kilometers per hour (43 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 distance varied from 30.1 meters (99 ft) to 38.4 meters (126 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 varied from 30.1 meters (99 ft) to 40.2 meters (132 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 231 newtons (52 lbf). After the vehicle was driven through 0.15 meter (6 in.) of water at 8 kilometers per hour (5 mph) for 2 minutes, the tests were repeated. The stopping distances and pedal force were essentially the same, indicating that the brakes had recovered on the first stop.

Parking brake. - Tests were conducted to determine parking brake effectiveness. The vehicle did not pass the parking brake test even after the brakes were adjusted and the tests repeated. The parking brakes would not hold the vehicle on the 30-percent slope with the vehicle in either position on the grade when a force of 400 newtons (90 lbf) was applied to the brake lever.

COMPONENT PERFORMANCE AND EFFICIENCY

Battery Charger

The battery charger for the Volkswagen Transporter is an off-board charger made by VARTA. It is a 380-volt, 50-hertz three-phase AC charger with a peak current input of 30 amperes. A thyrister bridge circuit controls the usage rate to maintain a constant average battery voltage. Timer 1 is started when the charge is started and terminates the charge in approximately 12 hours. In normal operation the charger takes about 14 hours with a 50-hertz supply to charge the battery. With the 60-hertz supply available in the United States the charge time was reduced accordingly. Timer 2 begins running only when the battery reaches the gassing voltage. This timer can be set for zero to 4 hours. Charging can be terminated by either timer, depending on the condition of the battery and the user's requirements. Both timers are automatically restored to their starting positions upon completion of charge.

Battery charger efficiency test data are presented in table VIII and in figure 13. The indicated efficiencies of the charger, as calculated from the readings on the industrial kilowatt-hour meter and the average values of charger output voltages and currents, are generally slightly higher than the efficiencies that were calculated from wattmeter readings. Which set of values is more nearly correct has not been determined. However, most readings are within 3 percent of each other. 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.

Slight changes in the applied voltage or slight variations in the battery voltage (due to temperature, age, etc.) can adversely affect the charging current and the time required to attain full charge. 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.

Battery

Manufacturer's data. - The battery supplied with the Volkswagen Transporter vehicle was composed of twenty-four 6-volt VARTA L800V3 lead-acid batteries connected in series. Each VARTA 6-volt battery is rated at 185 ampere-hours at the 5-hour discharge rate. Characteristics supplied by the battery manufacturer are shown in table IX.

The battery manufacturer's discharge data are presented in figures 14 and 15. Discharge current and voltage are shown as a function of time in figure 14. The battery can deliver 37 amperes for 5 hours (185 Ah) or 350 amperes for 0.25 hour (87.5 Ah). At a discharge current of 37 amperes, the cell voltage is 2.01 volts; at a discharge current of 350 amperes, the cell voltage drops to 1.77 volts.

Specific power versus the specific energy available for the 6-volt battery is shown in figure 15. At a low specific power of 6.7 watts per kilogram, the available energy is 0.126 megajoule per kilogram (35 Wh/kg). At a higher specific power of 60 watts per kilogram, the available energy decreases to 0.054 megajoule per kilogram (15 Wh/kg).

Battery acceptance. - Before the vehicle was road-tested, the battery supplied by the vehicle manufacturer was tested for terminal integrity and battery capacity as specified in appendix E of reference 1.

An electronic load bank was used to discharge the battery for the terminal test and the capacity check. since the load bank was limited to a discharge voltage of 120 volts, the Volkswagen Transporter battery pack was discharged in two subpacks, each with a nominal voltage of 72 volts.

The terminal integrity test (300 A) and the capacity check were performed during a single discharge. The results of these tests are presented in figure 16. The capacity removed is plotted as a function of battery voltage for both the front 72-volt and rear 72-volt battery subpacks. The front battery subpack (fig. 16(a)) was discharged at 300 amperes, followed by a 72-ampere discharge to a voltage of 61.5 volts. The rear battery subpack (fig. 16(b)) was discharged at 300 amperes, followed by a 36-ampere discharge to a voltage of 61.8 volts. The average capacity removed from both subpacks was 163 ampere-hours. As this is 88 percent of the rated capacity, the battery was acceptable.

The terminal temperature as measured by a thermocouple after the 300-ampere test varied from 3° C to 13° C above ambient. The battery passed both tests.

Battery performance at constant vehicle speed. - During the track tests, motor current and voltage were constantly monitored. Presented in figures 17 to 19 are the battery current, voltage, and power, respectively, measured during the 40-, 56-, and 69- kilometer-per-hour (25-, 35-, and 43-mph) range tests. The average battery current, voltage, and power during the first and last 25 percent of the vehicle range test are shown in table X. Battery power decreased toward the end of the test, probably because of the reduced power requirements as the temperature of the mechanical drive train components, tires, and associated lubricants increased during the test.

General battery performance. - Battery data for selected driving tests are shown in table XI. The electrolyte specific gravities ranged from 1.266 to 1.280 for the fully charged battery and from 1.130 to 1.135 for the discharged battery. The ampere-hour overcharge varied from 26 percent to 43 percent. While the overcharge was necessary to equalize the cells and assure full charge for every cell, it increased the total energy consumption. A charge cycle that results in only a 10-percent overcharge is more desirable.

The battery temperature had a tendency to increase from ambient at the start of the test to an average of 7 degrees Celsius (13 deg F) above ambient at the end of the test.

Battery efficiency. - One complete battery charge was analyzed to determine battery efficiency. This charge followed the 69-kilometer-per-hour (43-mph) constant-speed test conducted on 5/27/77.

Battery charger output voltage, current, and power are presented in figure 20 as a function of time. Total energy input to the battery during charging was 30.2 kilowatt-hours; the energy removed during the test was 17.9 kilowatt-hours. The battery energy efficiency is therefore 59 percent. However, as shown in table X, the ampere-hour overcharge was 43 percent for this test. Correcting for a more desirable overcharge of 10 percent reduces the battery charge energy to 23.2 kilowatt-hours and increases the battery energy efficiency to 77 percent. A similar analysis performed for the 40-kilometer-per-hour (25-mph) range test run on 6/8/77 shows an uncorrected battery energy efficiency of 62 percent with a 35 percent overcharge and a corrected energy efficiency of 77 percent with a 10 percent overcharge.

Controller

The Volkswagen Transporter controller is a DC chopper controller manufactured by Siemens AG. It controls the electric motor power in accordance with the desired driving conditions. The Siemens controller has a nominal rating of 144 volts and 321 amperes and weighs 50 kilograms (31.1 lbm). It is easily accessible through a small door located at the rear of the vehicle (fig. 21). As this vehicle is powered by a separately excited, shunt-wound DC motor, the controller consists of both an armature current control capable of handling armature currents of up to 320 amperes and a transistorized field control current regulator. In addition to maintaining the desired vehicle speed, the controller provides the following features:

1. If either the motor or controller overheats, the amount of power supplied to the motor is reduced.

2. If the battery voltage drops to a specified minimum value, the battery current is reduced.

3. If the battery voltage exceeds a specified limit during deceleration, regenerative braking is reduced.

4. Overcurrent protection in the armature cuts off motor current.

5. If any of the braking or driving control wires fail, all motor power is automatically cut off.

For speed regulation, the Volkswagen Transporter has armature control up to 22 kilometers per hour (14 mph); it then employs field control to a maximum speed of about 70 kilometers per hour. Figure 21 shows the controller installed in the rear of the vehicle.

Motor

The Volkswagen Transporter vehicle is powered by a separately excited, shunt-wound DC motor that was specially developed for the vehicle by Siemens AG. The motor is designed to be easily serviced. It is light in weight with a power-to-weight ratio of 0.188 kilowatt per kilogram. The motor is equipped with a forced-ventilation system in which a fan blows air in through the controller cooling fans and forces it axially through the motor. The blower becomes operative when the ignition key is turned on. It is powered by the main traction battery (144 V). The motor characteristics are

Maximum continuous rating, kW (hp). 16 (23)

Maximum peak rating, kW 32

Maximum speed, rpm 6700

Maximum torque at 2200 rpm, N-m 160

Number of poles 4

VEHICLE RELIABILITY

No major problems were encountered that prevented completion of the tests, although some minor problems occurred that delayed some tests. These problems were mostly related to the controller. On one occasion the 12-volt accessory battery was not being charged, so the 12-volt charger module in the controller had to be repaired. Another delay occurred when the vehicle would not operate over 22 kilometers per hour (14 mph). A malfunction in the field control circuit was limiting the vehicle speed. Some transistors were defective and had to be replaced.

Another problem was encountered when the battery was being recharged. The charger operates at too high a current when charging a fully discharged battery. As a result the battery overheated and would not cool down in time for the next scheduled test. The problem was corrected by passing cool air from an air conditioner over the battery after the charge was finished in order to reduce the cooling time. Other than these problems, the Volkswagen proved to be reliable throughout the test period.

DRIVER REACTION AND VEHICLE SERVICEABILITY

The vehicle was a comfortable, easy-to-handle vehicle at all speeds. Although it was seldom required, the removal of the propulsion battery is easy and can be accomplished in less than 5 minutes. The armature control, field control, logic components, DC-to-DC converter, and fuses are located in one unit on a slide-in tray that can be easily removed from the vehicle to simplify repairs.

APPENDIX A

VEHICLE SUMMARY DATA SHEET

1.0 Vehicle manufacturer: Volkswagen Werk AG
Wolfsburg, West Germany

2.0 Vehicle: conversion of standard VW Transporter (type 2)

3.0 Price and availability: on request

4.0 Vehicle weight and load

4.1	Curb weight, kg (lbm)	2268 (5000)
4.2	Gross vehicle weight, kg (lbm)	3075 (6780)
4.3	Cargo weight, kg (lbm)	603 (1330)
4.4	Number of passengers	3
4.5	Payload, kg (lbm)	807 (1780)

5.0 Vehicle size

5.1	Wheelbase, m (in.)	2.42 (95.5)
5.2	Length, m (ft)	4.44 (14.7)
5.3	Width, m (ft)	1.75 (5.7)
5.4	Height, m (in.)	
5.5	Head room, m (in.)	0.95 (37.5)
5.6	Leg room, m (in.)	0.66 (26)
5.7	Frontal area, m^2 (ft^2)	
5.8	Road clearance, m (in.)	
5.9	Number of seats	2 (1 single, 1 double)

6.0 Auxiliaries and options

6.1 Lights (number, type, and function): 2 head; 2 park and tail; 2 brake; 2 front parking; turn signals

6.2 Windshield wipers 2, on front windshield

6.3 Windshield washers yes

6.4 Defroster gasoline-electric (from heater)

6.5 Heater gasoline-electric

6.6 Radio yes

6.7 Fuel gage no

6.8 Amperemeter yes

6.9 Tachometer no

6.10 Speedometer yes, in km/h

6.11 Odometer yes, in km

6.12 Right- or left-hand drive left

6.13 Transmission no

6.14 Regenerative braking yes

6.15 Mirrors 3 rearview

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 6 V, lead acid, series connected; VARTA Batterie AG

7.1.2 Number of modules 24

7.1.3 Total number of cells 72

7.1.4 Operating voltage, V 144

7.1.5 Capacity, Ah 180

7.1.6 Overall battery size, m (in.) height, 0.30 (11.8); width, 0.933 (36.7); length, 1.454 (57.2)

7.1.7 Weight, kg (lbm) 850 (1874)

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

7.2 Auxiliary battery

7.2.1 Type and manufacturer lead acid, SLI; VARTA Batterie AG

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, 0.178 (7); width, 0.165 (6.5)

7.2.6 Weight, kg (lbm) 20.4 (45)

8.0 Controller

8.1 Type and manufacturer DC chopper; Siemens AG

8.2 Voltage rating, V 144

8.3 Current rating, A 320

8.4 Size, m (in.) height, 0.24 (9.5); width, 0.56 (22.0); length, 0.81 (32.0)

8.5 Weight, kg (lbm) 50 (110.2)

9.0 Propulsion motor

9.1 Type and manufacturer DC, shunt wound; Siemens AG

9.2 Insulation class IP R 24

9.3 Voltage rating, V 130

9.4 Current rating, A 150 (1-h rating)

9.5 Horsepower (rated), kW (hp) 16 (21.3) continuous (max. peak, 32 (42.6))

9.6 Size, m (in.) diameter, 0.364 (14.3); length, 0.454 (17.8)

9.7 Weight, kg (lbm) 87 (192)

9.8 Speed (rated), rpm 6700 (max. 8370)

10.0 Battery charger

10.1 Manufacturer VARTA Batterie AG

10.2 Type off board

10.3 Input voltage required, V 380 AC (3 phase)

10.4 Peak current demand, A 30

10.5 Recharge time, h 12

10.6 Size, m (in.) height, 0.864 (34.0); width, 0.406 (16.0); length, 0.559 (22.0)

10.7 Weight, kg (lbm)

10.8 Automatic turnoff feature timer

11.0 Body

11.1 Manufacturer and type Volkswagen Transporter (type 2)

11.2 Materials steel

11.3 Number of doors and type 2 regular; 2 sliding

11.4 Number of windows and type 7 plus windshield; glass

11.5 Number of seats and type 1 bucket; 1 double bucket

11.6 Cargo space volume, m^3 (ft^3) 5.3 (187.2)

11.7 Cargo space dimensions, m (in.) 2.80×1.54×1.23 (110.2×60.6×48.4)

12.0 Chassis

12.1 Frame

12.1.1 Type and manufacturer Volkswagen Transporter (type 2)

12.1.2 Materials steel

12.1.3 Modifications battery compartment under cargo area

12.2 Springs and shocks

12.2.1 Type and manufacturer not specified

12.2.2 Modifications none

12.3 Axles

12.3.1 Manufacturer not specified

12.3.2 Front

12.3.3 Rear

12.4 Transmission

12.4.1 Type and manufacturer none

12.4.2 Gear ratios ______

12.4.3 Driveline ratio ______

12.5 Steering

12.5.1 Type and manufacturer ______

12.5.2 Turning ratio ______

12.5.3 Turning diameter, m (ft) 11.9 (39)

12.6 Brakes

12.6.1 Front disk

12.6.2 Rear drum

12.6.3 Parking mechanical, on rear wheels

12.6.4 Regenerative yes

12.7 Tires

12.7.1 Manufacturer and type steel-belted radial

12.7.2 Size 185R14

12.7.3 Pressure, kPa (psi):

Front 271 (45)

Rear 319 (53)

12.7.4 Rolling radius, m (in.) 0.316 (12.45)

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) 70.8 (44)

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

13.3 Tested at cruise speed, km/h (mph) 69 (43); 56 (35); 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 the vehicle arrived 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. The fifth-wheel distance counter and ampere-hour integrator counter were reset to zero. 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 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. These data were obtained from the control tower, which was located in the center of the test track. 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 under 11 kilometers per hour (7 mph).

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. 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 VOLKSWAGEN TRANSPORTER

(a) SI units

Test date	Test condition (constant speed, km/h; or driving schedule)	Wind velocity, km/h	Temperature, °C	Range, km	Cycle life, number of cycles	Capacity out of batteries, Ah	Capacity into batteries, Ah	Energy into charger, MJ	Indicated energy consumption, MJ/km
5/11/77	40.2	8	19	110.2	----	156.3	208 9	------	----
5/24/77	40 2	8	27	124.7	----	162.2	213 5	142.2	1.14
6/1/77	[a]40.2	3 2 - 14.5	23	116.7	----	163 3	220.5	------	----
6/8/77	40.2	6.4 - 12.9	16	118 7	----	162 5	219.6	[b]155.1	1.32
5/12/77	56.3	9.6	23	89.0	----	147 3	201 2	------	----
5/31/77	56.3	12.9 - 16.1	23	85.1	----	131.5	185.6	123 8	1.45
5/16/77	69 2	8	25	57.1	----	111.8	175 3	------	----
5/23/77	69.2	4.8	22	60.7	----	----	----	100.4	1 66
5/27/77	69.2	4.8	22	71 8	----	132 0	188.8	------	----
5/26/77	B[c]	8	22	71 1	197	162 7	200.6	130.3	1 83
6/7/77	B[c]	8 - 16 1	14	64.5	193	154 8	201.6	[b]140 7	2 17
5/17/77	B[d]	9.6	27	68.5	179	163.8	215.5	------	----
5/18/77	B[d]	8	29	75.8	215	170.4	----	144.3	1.95
6/9/77	B[d]	12.9 - 16 1	13	70.5	207	165 6	230 3	[b]161.6	2.28
6/2/77	C[c]	11.3	19	48.1	81	135.7	170 0	------	----
6/3/77	C[c]	8	14	46.3	78	122 5	191.3	108.0	2.33
5/20/77	C[d]	3 2	27	46.7	75	127.8	----	------	----
5/25/77	C[d]	11.3	25	48 4	78	132 2	168.2	112 7	2 33

(b) U S customary units

Test date	Test condition (constant speed, mph; or driving schedule)	Wind velocity, mph	Temperature, °F	Range, miles	Cycle life, number of cycles	Capacity out of batteries, Ah	Capacity into batteries, Ah	Energy into charger, kWh	Indicated energy consumption, kWh/mile
5/11/77	25	5	66	68 5	----	156.3	208 9	------	----
5/24/77	25	5	81	77.5	----	162.2	213.5	39.5	0 51
6/1/77	[a]25	2 - 9	73	72.5	----	163 3	220.5	------	----
6/8/77	25	4 - 8	60	73.8	----	162.5	219 5	[b]43.1	.59
5/12/77	35	6	74	55 3	----	147 3	201.6	------	----
5/31/77	35	8 - 10	74	62.9	----	131 5	185 6	34 4	.65
5/16/77	43	5	77	35.5	----	111.8	175.3	------	----
5/23/77	43	3	72	37.7	----	----	----	27.9	.74
5/27/77	43	3	71	44 6	----	132.0	188 8	------	----
5/26/77	B[c]	5	71	44.2	197	162.7	200.6	36.2	.82
6/7/77	B[c]	5 - 10	58	40.1	193	154.8	201.6	[b]39.1	.97
5/17/77	B[d]	6	81	42.5	179	163.8	215.5	------	----
5/18/77	B[d]	5	84	47.1	215	170.4	----	40.1	.87
6/9/77	B[d]	8 - 10	56	43.8	207	165.6	230.3	[b]44.9	1.02
6/2/77	C[c]	7	66	29.9	81	135.7	170.0	------	----
6/3/77	C[c]	5	57	28.8	78	122.5	191.3	30.0	1.04
5/20/77	C[d]	2	80	29.0	75	127.8	----	------	----
5/25/77	C[d]	7	77	30.1	78	132.2	168 2	31.3	1.04

[a]Speed controlled with potentiometer.

[b]Read with industrial kilowatt-hour meter.

[c]Without regenerative braking.

[d]With regenerative braking.

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TABLE II. - ACCELERATION TIMES FOR VOLKSWAGEN TRANSPORTER

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	.8	.6	.6
4.0	2.5	1.3	1.1	1.1
6.0	3.7	1.8	1.6	1.5
8.0	5.0	2.2	1.9	2.0
10.0	6.2	2.6	2.2	2.3
12.0	7.5	3.0	2.7	2.7
14.0	8.7	3.4	3.1	3.1
16.0	9.9	3.8	3.5	3.5
18.0	11.2	4.1	3.9	3.9
20.0	12.4	4.5	4.2	4.4
22.0	13.7	4.9	4.5	4.6
24.0	14.9	5.4	5.0	5.0
26.0	16.2	5.9	5.6	5.5
28.0	17.4	6.3	6.2	6.0
30.0	18.7	6.8	6.8	6.7
32.0	19.9	7.5	7.5	7.4
34.0	21.1	8.0	8.2	8.1
36.0	22.4	8.9	9.2	8.8
38.0	23.6	9.5	10.1	9.7
40.0	24.9	10.3	10.7	10.7
42.0	26.1	11.3	11.9	11.6
44.0	27.4	12.3	12.8	12.7
46.0	28.6	13.3	13.6	13.7
48.0	29.8	14.5	15.0	14.9
50.0	31.1	15.8	16.2	16.4
52.0	32.3	17.2	17.2	17.8
54.0	33.6	18.7	18.3	19.4
56.0	34.8	20.3	20.0	21.2
58.0	36.1	22.1	21.9	23.2
60.0	37.3	24.1	24.3	25.7
62.0	38.5	26.6	26.5	28.2
64.0	39.8	29.3	28.9	31.3
66.0	41.0	31.8	32.2	34.6
68.0	42.3	----	35.6	38.3

TABLE III. - ACCELERATION CHARACTERISTICS FOR VOLKSWAGEN TRANSPORTER

Vehicle speed		Amount of discharge, percent					
km/h	mph	0		40		80	
		Acceleration					
		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	.9	1.9	1.1	2.4	1.1	2.4
4.0	2.5	1.1	2.5	1.2	2.7	1.3	3.0
6.0	3.7	1.4	3.0	1.5	3.3	1.3	2.9
8.0	5.0	1.4	3.1	1.7	3.8	1.4	3.2
10.0	6.2	1.3	2.9	1.4	3.1	1.5	3.4
12.0	7.5	1.3	3.0	1.3	3.0	1.4	3.1
14.0	8.7	1.6	3.5	1.4	3.1	1.5	3.3
16.0	9.9	1.7	3.7	1.4	3.1	1.4	3.1
18.0	11.2	1.6	3.5	1.5	3.3	1.3	2.8
20.0	12.4	1.5	3.3	1.8	4.0	1.6	3.7
22.0	13.7	1.3	2.8	1.6	3.5	1.7	3.8
24.0	14.9	1.1	2.5	1.0	2.4	1.2	2.7
26.0	16.2	1.3	2.8	1.0	2.2	1.1	2.5
28.0	17.4	1.3	2.9	.9	2.0	1.0	2.2
30.0	18.7	.9	2.1	.8	.9	.8	1.8
32.0	19.9	.9	2.1	.8	1.8	.8	1.7
34.0	21.1	.9	2.0	.7	1.5	.8	1.8
36.0	22.4	.8	1.7	.6	1.4	.7	1.7
38.0	23.6	.8	1.7	.8	1.7	.6	1.4
40.0	24.9	.6	1.4	.7	1.5	.6	1.3
42.0	26.1	.6	1.3	.6	1.2	.6	1.2
44.0	27.4	.5	1.2	.7	1.5	.5	1.2
46.0	28.6	.5	1.1	.5	1.2	.5	1.1
48.0	29.8	.4	1.0	.4	.9	.4	.9
50.0	31.1	↓	.9	.5	1.1	.4	.9
52.0	32.3	↓	.9	.5	1.2	.4	.8
54.0	33.6	↓	.8	.4	.9	.3	.7
56.0	34.8	.3	.7	.3	.7	.3	.7
58.0	36.1	.3	.6	.3	.6	.3	.6
60.0	37.3	.3	.6	.2	.5	.2	.5
62.0	38.5	.2	.5	↓	.5	.2	.4
64.0	39.8	.2	.5	↓	.4	.2	.4
66.0	41.0	.2	.5	↓	.4	.2	.4
68.0	42.3	---	---	↓	.4	.1	.3
						---	---

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TABLE IV. - GRADEABILITY OF VOLKSWAGEN TRANSPORTER

Vehicle speed		Amount of discharge, percent		
km/h	mph	0	40	80
		Gradeability, percent		
0	0	0	0	0
2.0	1.2	8.8	10.9	10.9
4.0	2.5	11.5	12.4	14.0
6.0	3.7	14.1	15.5	13.4
8.0	5.0	14.4	17.6	14.7
10.0	6.2	13.4	14.6	15.8
12.0	7.5	13.7	13.7	14.7
14.0	8.7	16.1	14.1	15.2
16.0	9.9	17.2	14.3	14.2
18.0	11.2	16.2	15.3	12.9
20.0	12.4	15.1	18.6	17.0
22.0	13.7	13.0	16.3	17.6
24.0	14.9	11.5	11.0	12.6
26.0	16.2	13.1	10.0	11.5
28.0	17.4	13.5	9.0	10.0
30.0	18.7	9.6	8.7	8.3
32.0	19.9	9.7	8.3	7.9
34.0	21.1	9.1	6.9	8.1
36.0	22.4	7.7	6.2	7.5
38.0	23.6	8.0	7.8	6.3
40.0	24.9	6.5	6.9	5.9
42.0	26.1	5.9	5.7	5.7
44.0	27.4	5.6	6.9	5.5
46.0	28.6	5.1	5.5	5.1
48.0	29.8	4.6	4.3	4.2
50.0	31.1	4.3	5.3	4.0
52.0	32.3	3.9	5.5	3.8
54.0	33.6	3.6	4.2	3.4
56.0	34.8	3.4	3.2	3.1
58.0	36.1	3.0	2.7	2.6
60.0	37.3	2.6	2.5	2.3
62.0	38.5	2.2	2.5	2.0
64.0	39.8	2.2	2.0	1.8
66.0	41.0	2.2	1.7	1.6
68.0	42.3	----	1.7	1.5

TABLE V. - ROAD ENERGY CONSUMPTION FOR VOLKSWAGEN TRANSPORTER

(a) With rear axle connected

Vehicle speed		Road energy consumed	
km/h	mph	MJ/km	kWh/mile
68.0	42.3	0	0
66.0	41.0	.81	.36
64.0	39.8	.84	.38
62.0	38.5	.90	.40
60.0	37.3	.80	.36
58.0	36.0	.72	.32
56.0	34.8	.74	.33
54.0	33.6	.82	.37
52.0	32.3	.81	.36
50.0	31.1	.72	.32
48.0	29.8	.70	.31
46.0	28.6	.72	.32
44.0	27.3	.74	.33
42.0	26.1	.70	.31
40.0	24.9	.67	.30
38.0	23.6	.67	.30
36.0	22.4	.68	.30
34.0	21.1	.65	.29
32.0	19.9	.64	.28
30.0	18.6	.62	.28
28.0	17.4	.57	.26
26.0	16.2	.55	.24
24.0	14.9	.55	.24
22.0	13.7	.55	.24
20.0	12.4	.54	.24
18.0	11.2	.52	.28
16.0	9.9	.45	.20
14.0	8.7	.42	.19
12.0	7.5	.43	.19
10.0	6.2	.43	.19
8.0	5.0	.40	.18
6.0	3.7	.38	.17
4.0	2.5	.36	.16
2.0	1.2	.39	.18

(b) With rear axle disconnected

Vehicle speed		Road energy consumed	
km/h	mph	MJ/km	kWh/mile
72.0	44.7	0	0
70.0	43.5	.62	.28
68.0	42.3	.59	.26
66.0	41.0	.57	.25
64.0	39.8	.56	.25
62.0	38.5	.57	.26
60.0	37.3	.47	.21
58.0	36.0	.43	.19
56.0	34.8	.52	.23
54.0	33.6	.54	.24
52.0	32.3	.55	.25
50.0	31.1	.56	.25
48.0	29.8	.54	.24
46.0	28.6	.46	.20
44.0	27.3	.44	.20
42.0	26.1	.48	.21
40.0	24.9	.43	.19
38.0	23.6	.34	.15
36.0	22.4	.37	.17
34.0	21.1	.41	.18
32.0	19.9	.41	.19
30.0	18.6	.41	.18
28.0	17.4	.34	.15
26.0	16.2	.30	.18
24.0	14.9	.30	.13
22.0	13.7	.32	.14
20.0	12.4	.35	.16
18.0	11.2	.34	.15
16.0	9.9	.30	.13
14.0	8.7	.31	.14
12.0	7.5	.30	.13
10.0	6.2	.29	.13
8.0	4.0	.31	.14
6.0	3.7	.31	.14
4.0	2.5	.29	.13
2.0	1.2	.29	.13

TABLE VI. - ROAD POWER REQUIREMENTS OF VOLKSWAGEN TRANSPORTER

(a) With rear axle connected

Vehicle speed		Road power required	
km/h	mph	kW	hp
68.0	42.3	0	0
66.0	41.0	14.8	19.9
64.0	39.8	15.0	20.1
62.0	38.5	15.5	20.7
60.0	37.3	13.4	18.0
58.0	36.0	11.7	15.6
56.0	34.8	11.4	15.3
54.0	33.6	12.3	16.5
52.0	32.3	11.7	15.7
50.0	31.6	10.9	13.4
48.0	29.8	9.4	12.5
46.0	28.6	9.2	12.3
44.0	27.3	8.0	12.1
42.0	26.1	8.2	10.9
40.0	24.9	7.4	9.9
38.0	23.6	7.0	9.4
36.0	22.4	6.8	9.1
34.0	21.1	6.1	8.2
32.0	19.9	5.7	7.6
30.0	18.6	5.2	7.0
28.0	17.4	4.4	6.0
26.0	16.2	4.0	5.3
24.0	14.9	3.6	4.9
22.0	13.7	3.3	4.5
20.0	12.4	3.0	4.0
18.0	11.2	2.6	3.5
16.0	9.9	2.0	2.7
14.0	8.7	1.6	2.2
12.0	7.5	1.4	1.9
10.0	6.2	1.2	1.6
8.0	5.0	.9	1.2
6.0	3.7	.6	.8
4.0	2.5	.4	.5
2.0	1.2	.2	.3

(b) With rear axle disconnected

Vehicle speed		Road power required	
km/h	mph	kW	hp
72.0	44.7	0	0
70.0	43.5	12.0	16.1
68.0	42.3	11.1	14.9
66.0	41.0	10.4	13.9
64.0	39.8	10.0	13.4
62.0	38.5	10.1	13.6
60.0	37.3	7.8	10.5
58.0	36.0	6.9	9.3
56.0	34.8	8.1	10.9
54.0	33.6	8.2	10.9
52.0	32.3	8.0	10.7
50.0	31.1	7.7	10.4
48.0	29.8	7.2	9.6
46.0	28.6	5.8	7.8
44.0	27.3	5.4	7.3
42.0	26.1	5.6	7.5
40.0	24.9	4.8	6.4
38.0	23.6	3.6	4.8
36.0	22.4	3.7	5.0
34.0	21.1	3.9	5.2
32.0	19.9	3.7	4.9
30.0	18.6	3.4	4.6
28.0	17.4	2.7	3.6
26.0	16.2	2.1	2.9
24.0	14.9	2.0	2.7
22.0	13.7	1.9	2.6
20.0	12.4	1.9	2.6
18.0	11.2	1.7	2.2
16.0	9.9	1.3	1.8
14.0	8.7	1.2	1.6
12.0	7.5	1.0	1.3
10.0	6.2	.8	1.1
8.0	5.0	.7	.9
6.0	3.7	.5	.7
4.0	2.5	.3	.4
2.0	1.2	.2	.2

TABLE VII. - INDICATED ENERGY CONSUMPTION FOR

VOLKSWAGEN TRANSPORTER

Test condition (constant speed or driving schedule)		Indicated energy consumption	
km/h	mph	MJ/km	kWh/mile
40.2	25	1.14	0.51
56.3	35	1.45	.65
69.2	43	1.66	.74
B[a]		2.00	.95
B[b]		2.11	.89
C[a]		2.33	1.04
C[b]		2.33	1.04

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

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TABLE VIII. - CHARGER EFFICIENCY TEST DATA FOR VOLKSWAGEN TRANSPORTER

Time	Input power from kilowatt-hour meter, P_{in}, kW	Output power calculated from $V_{av} \times I_{av}$, P_{out}, kW	Energy efficiency, percent	Input power from watt-meter, P_{in}, kW	Output power from watt-meter, P_{out}, kW	Power efficiency, percent	Deviation, percent
6:45 a.m.	3.63	2.96	81.5	3.30	2.60	78.8	3.3
7:45	3.53	2.91	82.4	3.16	2.56	81.0	1.7
8:45	3.41	2.67	78.3	3.23	2.52	78.0	.4
9:45	3.39	2.79	82.3	3.10	2.54	81.9	.5
10:45	3.27	2.75	84.1	3.10	2.45	79.0	6.0
11:45	3.13	2.68	85.6	2.94	2.39	81.3	5.0
12:45 p.m.	2.98	2.52	84.6	2.80	2.25	80.4	4.9
1:45	2.80	2.38	85.0	2.44	2.07	84.8	.2
2:45	2.52	2.15	85.3	2.24	1.86	83.3	2.3
3:45	2.29	1.99	86.9	2.00	1.71	85.3	1.8
4:45	2.27	1.96	86.3	1.97	1.65	83.8	2.9
5:45	2.27	1.93	85.0	1.86	1.62	86.9	2.2
6:45	2.34	2.02	86.3	2.01	1.72	85.7	.7

TABLE IX. - CHARACTERISTICS OF VARTA L800V3

BATTERY MODULES USED IN VW TRANSPORTER

Length, cm (in.)	24 (9.4)
Width, cm (in.)	19 (7.5)
Height, cm (in.)	27 (10.6)
Weight, kg (lbm)	30 (66)

TABLE X. - AVERAGE BATTERY PERFORMANCE DURING CONSTANT-SPEED TESTS OF

VOLKSWAGEN TRANSPORTER

Test speed		Initial 25 percent of test			Final 25 percent of test		
km/h	mph	Current, A	Voltage, V	Power, kW	Current, A	Voltage, V	Power, kW
40	25	56	147	8.2	58	130	7.7
56	35	87	144	12.4	90	123	11.6
69	43	138	141	19.4	122	120	15.9

TABLE XI. - VOLKSWAGEN TRANSPORTER BATTERY VEHICLE TEST DATA

Test condition (constant speed or driving schedule)		Test date	Battery capacity, Ah		Overcharge, percent	Electrolyte specific gravity		Average battery temperature, °C	
km/h	mph		Input	Output		Before test	After test	Before test	After test
69	45	5/27/77	189	132	43	1.266	1.135	32	38
56	35	5/31/77	185	132	40	1.272	1.130	24	30
C		6/2/77	170	135	26	1.278	1.135	32	41
40	25	6/8/77	220	163	35	1.270	1.130	33	32
B		6/9/77	230	166	39	1.280	1.o30	32	35

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Figure 1. - Volkswagen Transporter electric delivery van.

Figure 2. - Side view of VW Transporter showing special fixture for removal of battery pack.

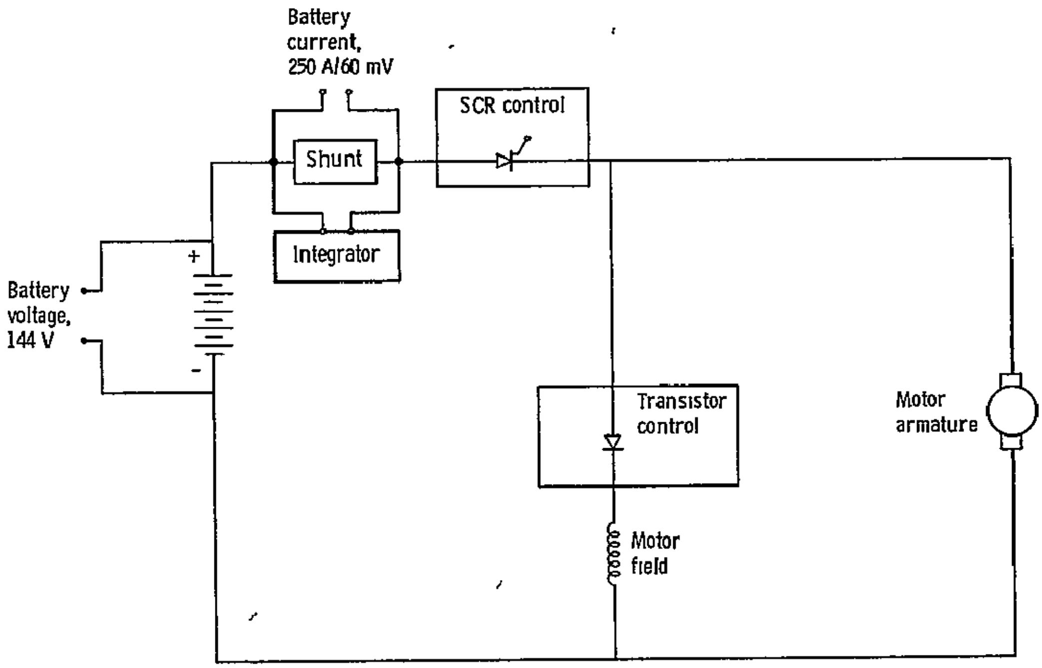
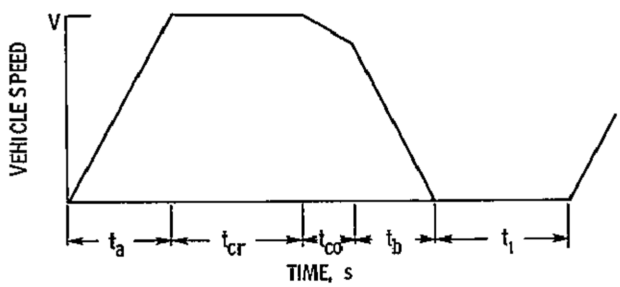


Figure 3 - Wiring diagram of VW Transporter showing instrumentation locations.



TEST PARAMETER	SAE SCHEDULES		
	B	C	D
MAX. SPEED, V, mph	20	30	45
ACCEL. TIME, t_a, s	19	18	28
CRUISE TIME, t_{cr}	19	20	50
COAST TIME, t_{co}	4	8	10
BRAKE TIME, t_b	5	9	9
IDLE TIME, t_i	25	25	25

Figure 4 - SAE J227a driving cycle schedules

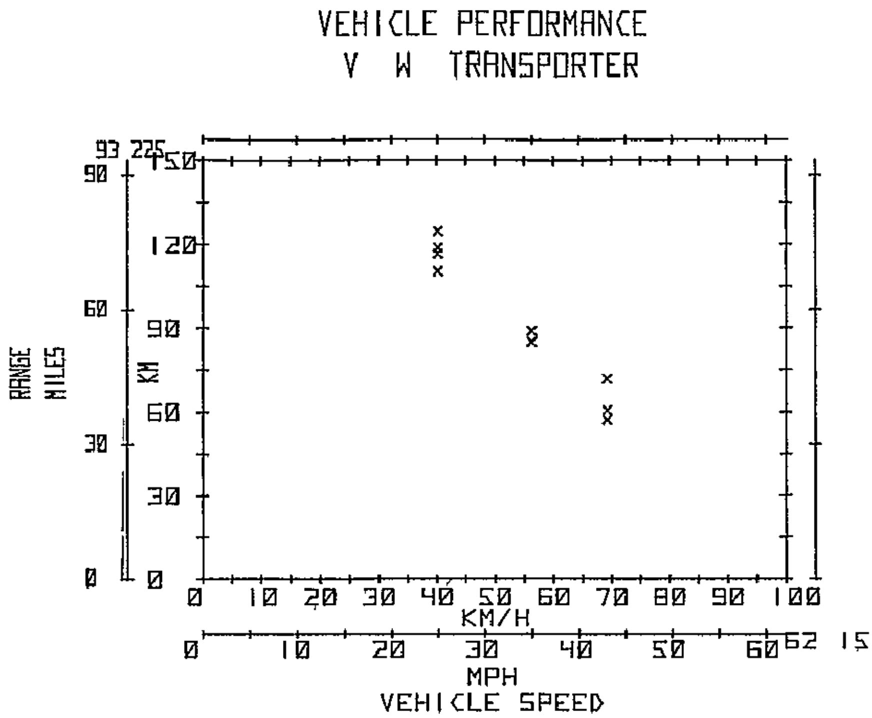


Figure 5. - Range at constant speed.

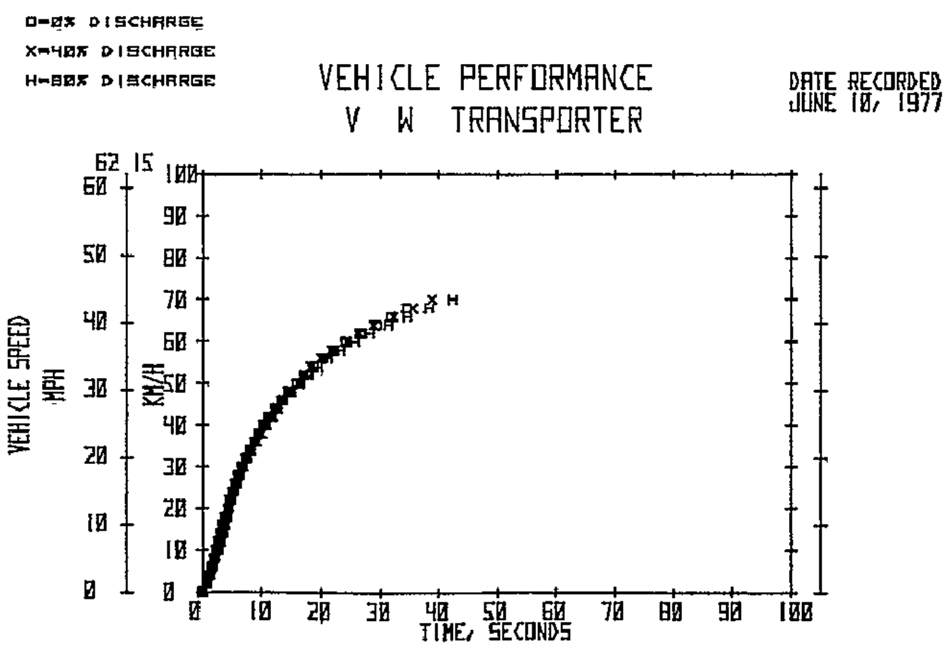


Figure 6. - Vehicle acceleration.

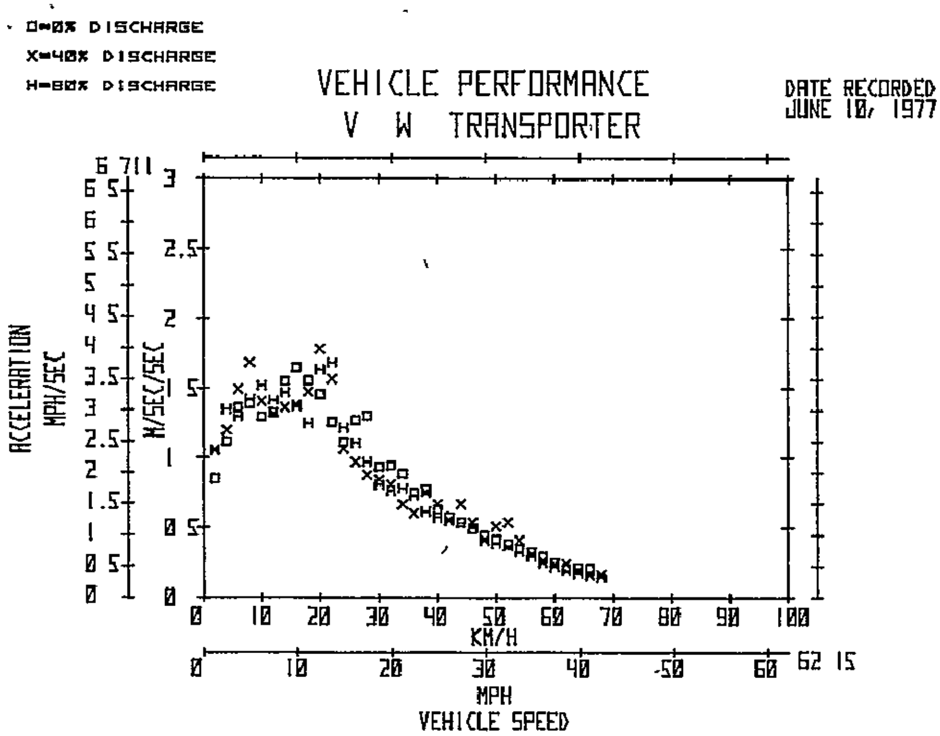


Figure 7 - Acceleration as a function of speed.

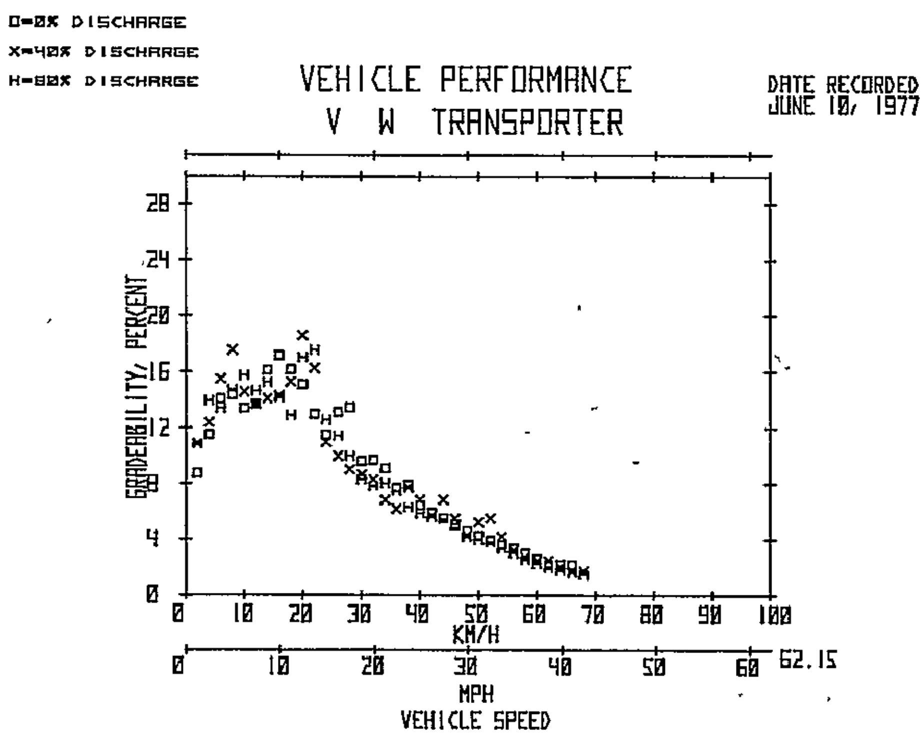
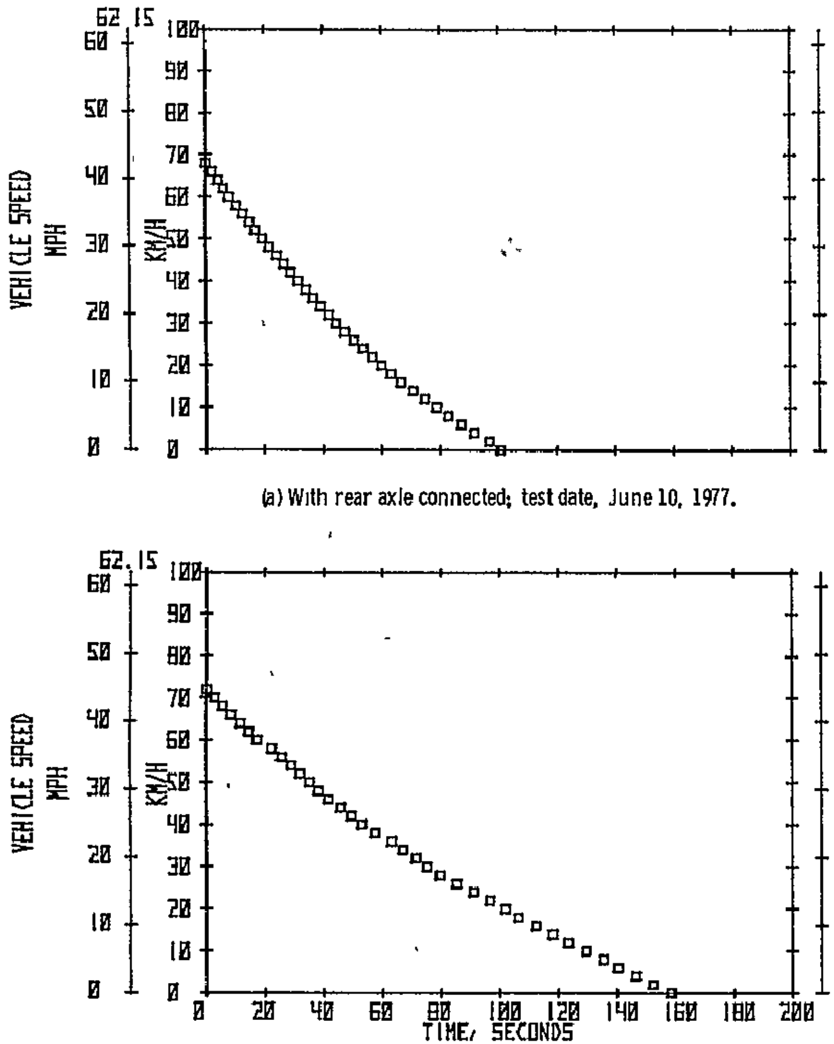


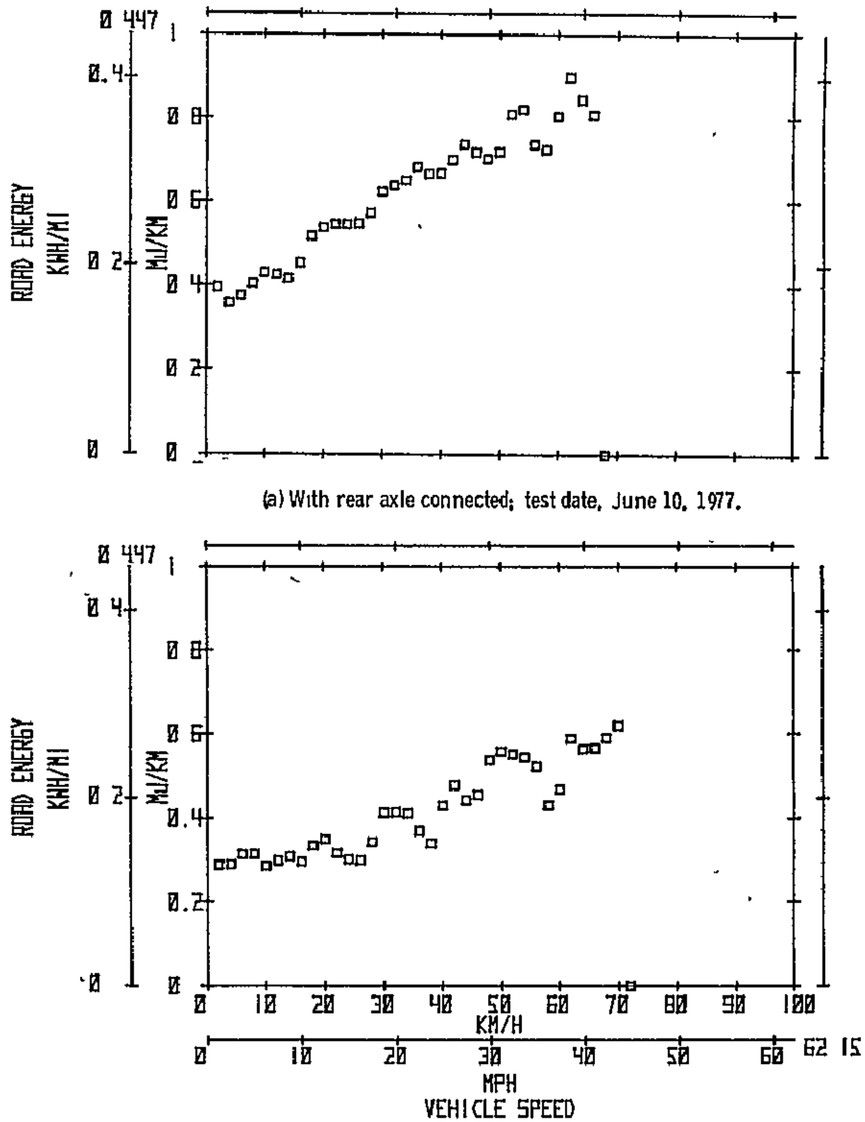
Figure 8. - Gradeability as a function of speed.



(a) With rear axle connected; test date, June 10, 1977.

(b) With rear axle disconnected, test date, June 21, 1977.

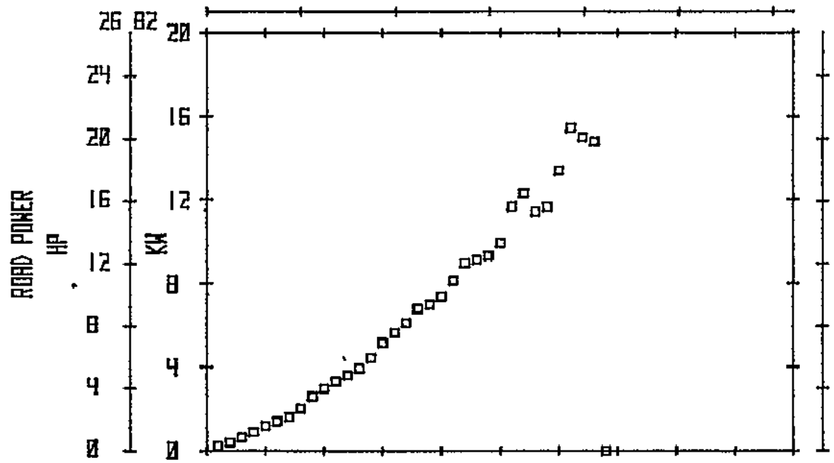
Figure 9. - Vehicle deceleration for Volkswagen Transporter.



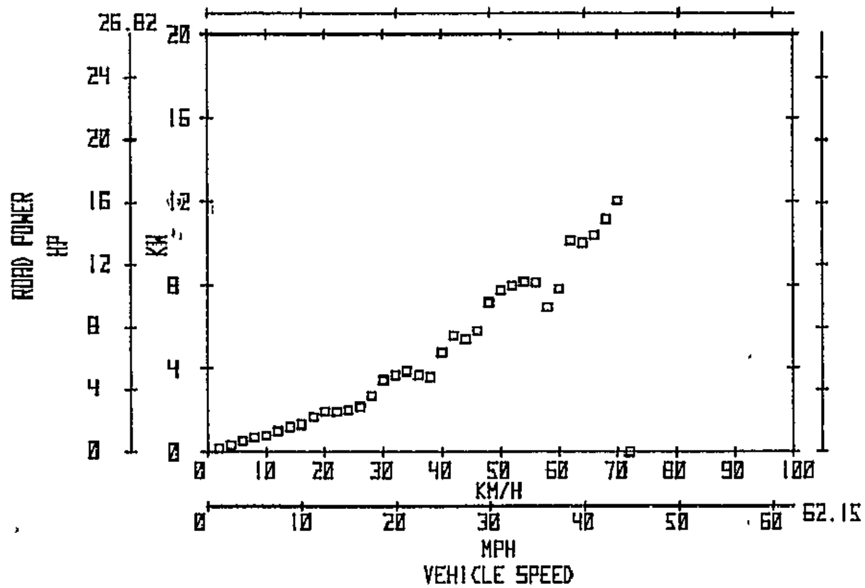
(a) With rear axle connected; test date, June 10, 1977.

(b) With rear axle disconnected, test date, June 21, 1977.

Figure 10. - Road energy as a function of speed for Volkswagen Transporter.



(a) With rear axle connected, test date, June 10, 1977.



(b) With rear axle disconnected, test date, June 21, 1977.

Figure 11. - Road power as a function of speed for Volkswagen Transporter.

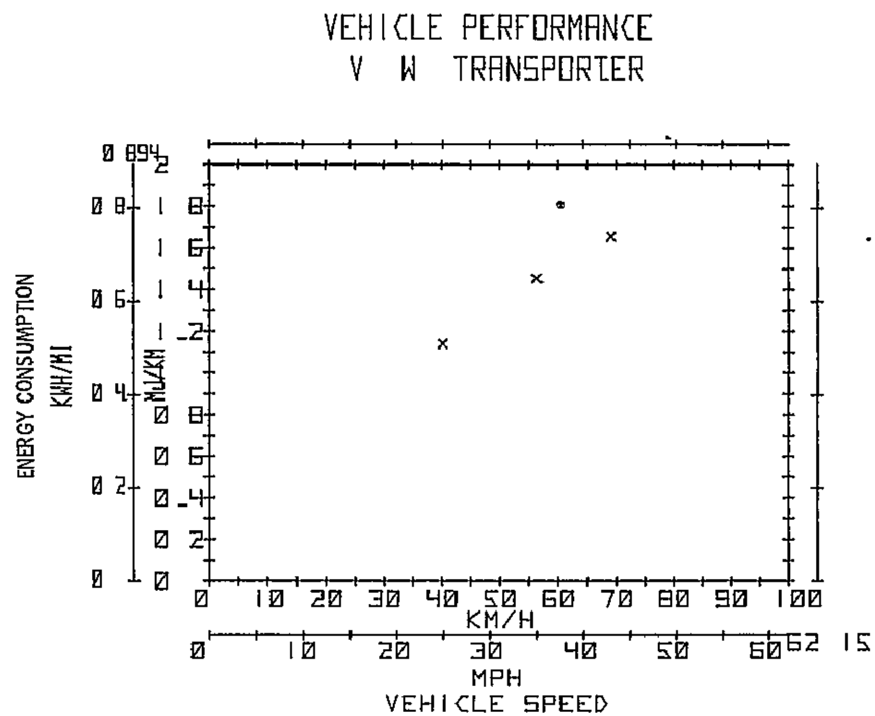


Figure 12. - Energy consumption as a function of speed.

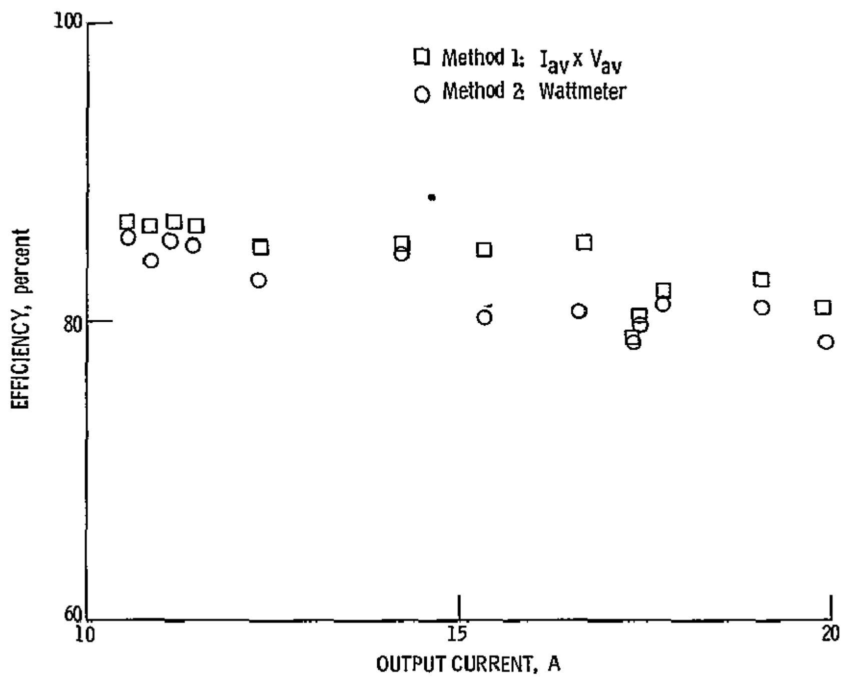


Figure 13. - Battery charger efficiency as a function of output current for Volkswagen Transporter

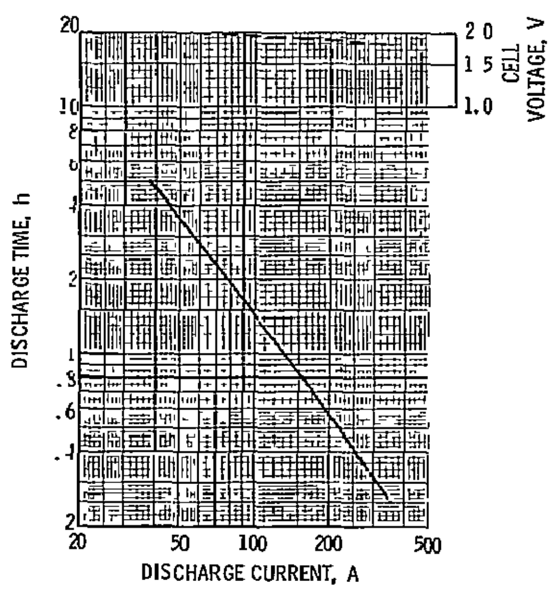


Figure 14. - Discharge characteristics of VARTA L800V3 battery

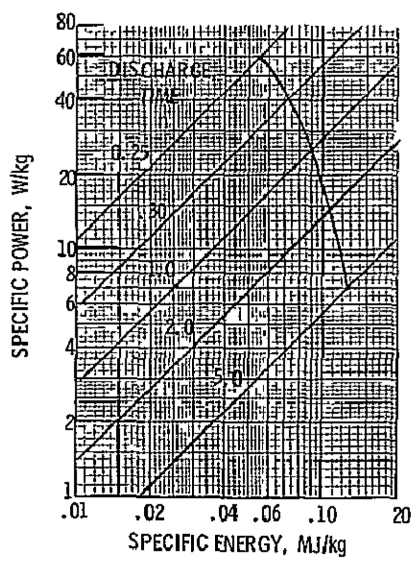
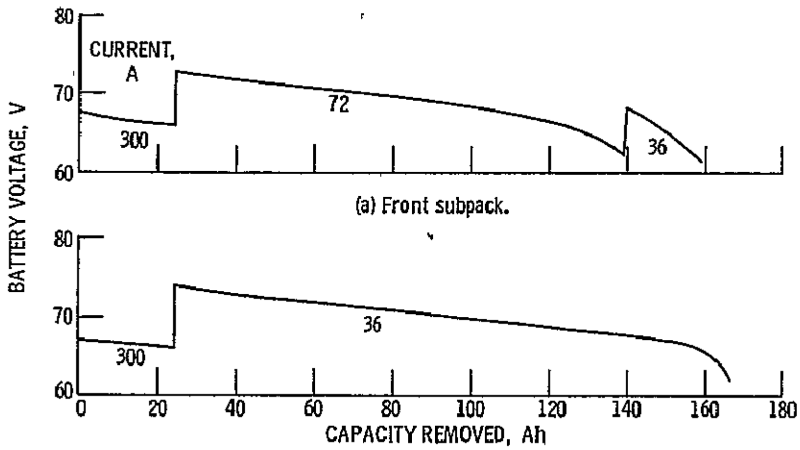


Figure 15. - Energy/power relationship for VARTA L800V3 three-cell battery.



(b) Rear subpack

Figure 16 - Battery qualification test data for VARTA L800V3.

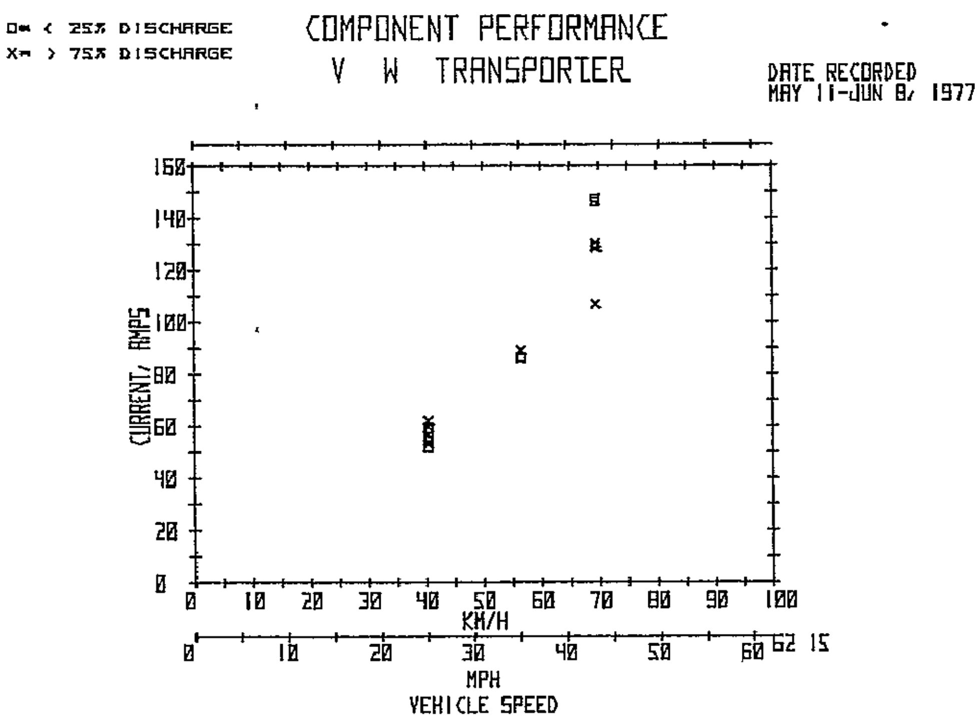


Figure 17. - Current as a function of speed.

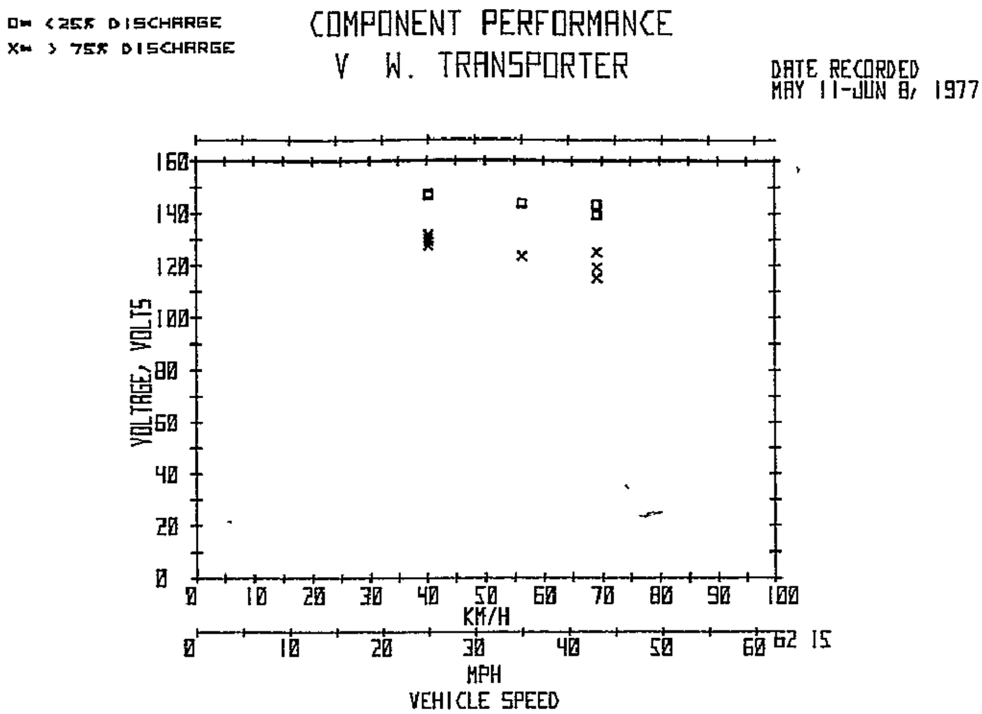


Figure 18. - Voltage as a function of speed.

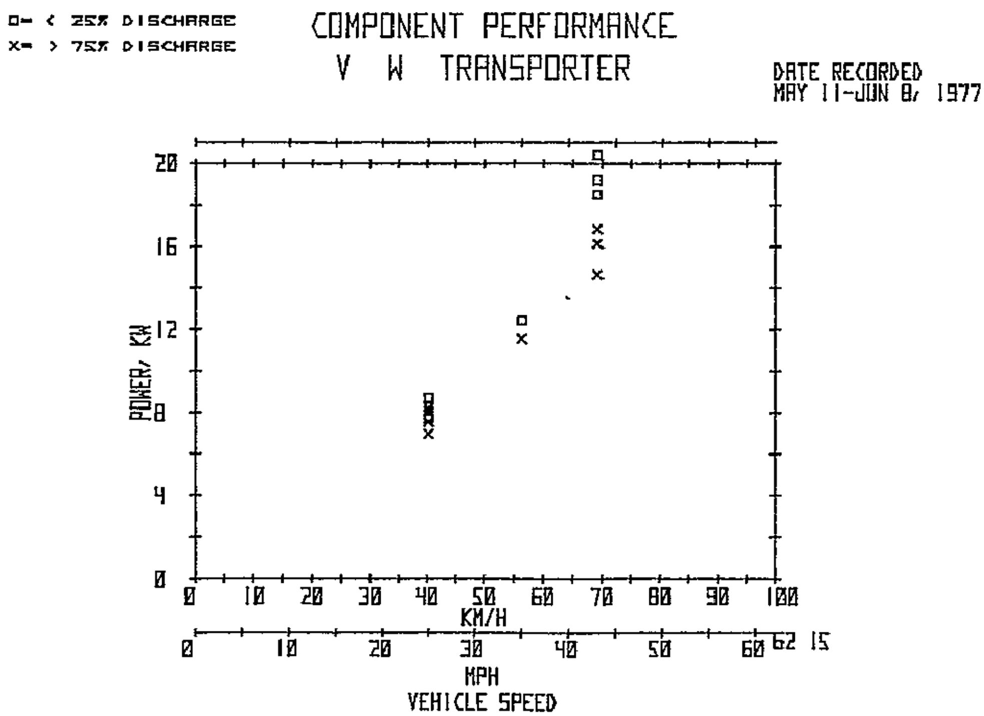


Figure 19. - Power as a function of speed.

Figure 21. - Controller installed in Volkswagen Transporter.

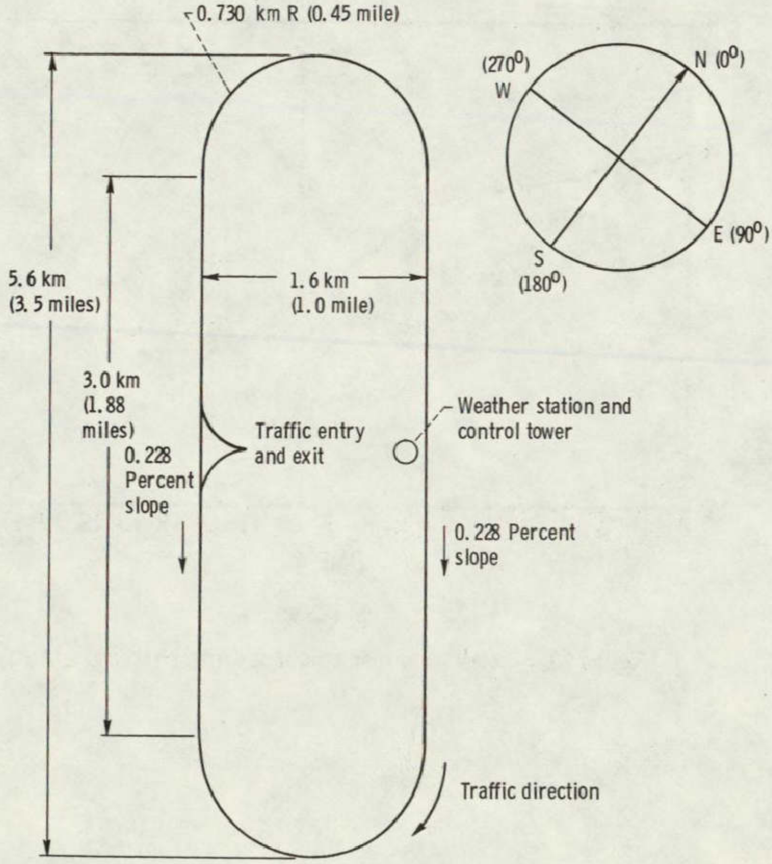
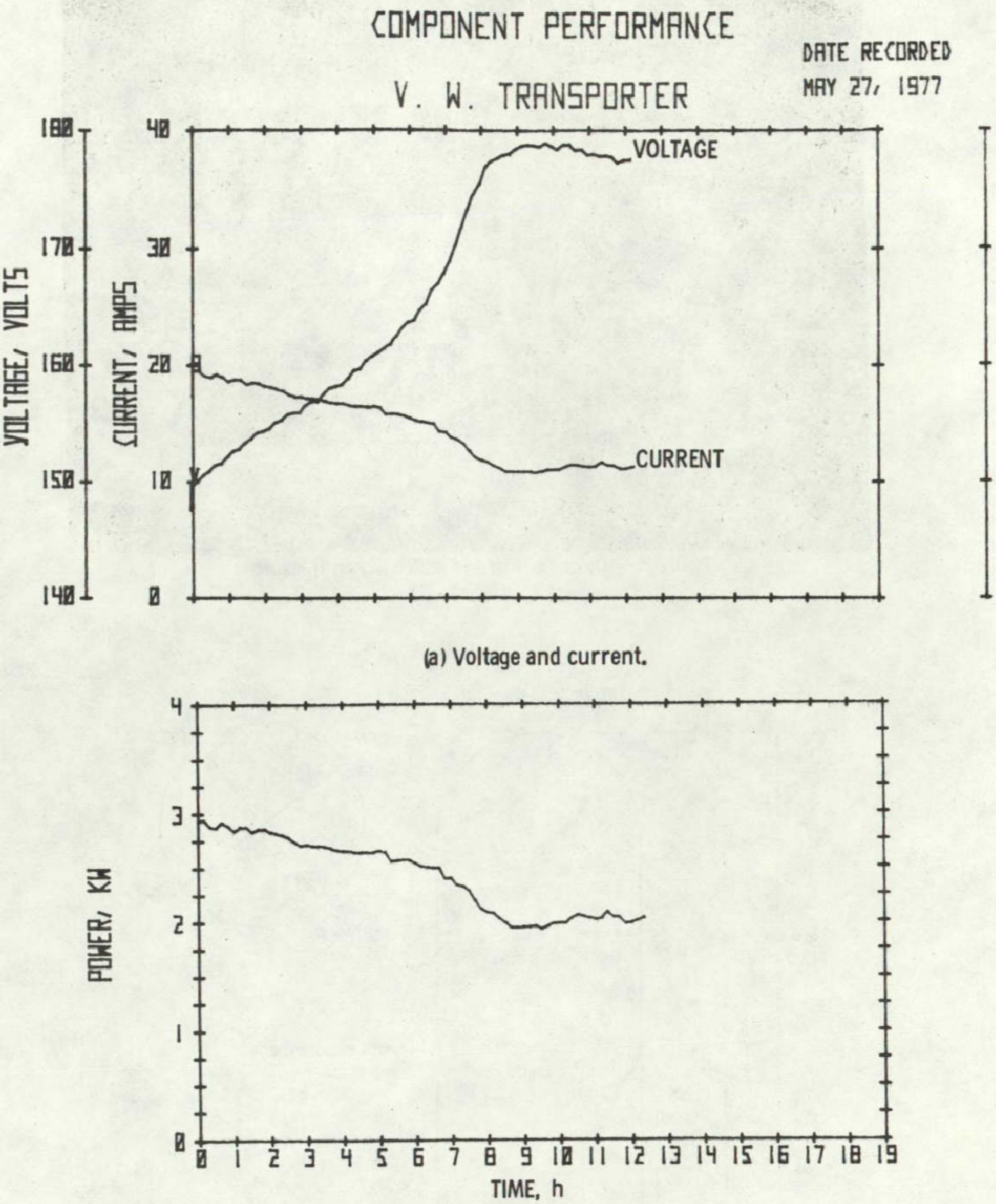


Figure B-1. - Characteristics of Transportation Research Center Test Track, East Liberty, Ohio.



(a) Voltage and current.

(b) Power.

Figure 20. - Battery charger output voltage, current, and power.

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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, °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 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.

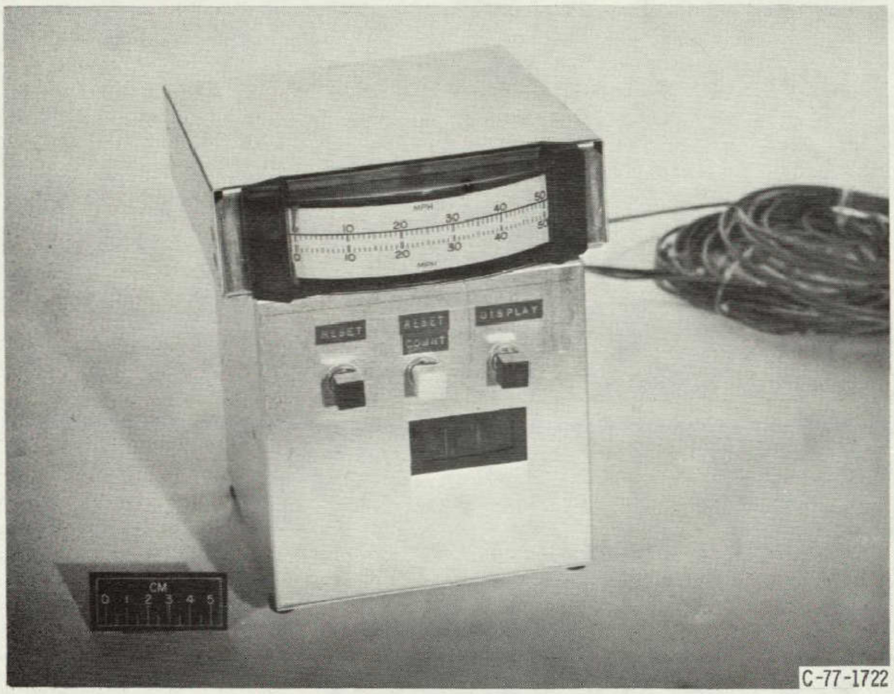

Figure C-8. - Cycle timer.