5030-519

Electric & Hybrid Vehicle System
Research & Development Project

DOE/CS-54209-5
Distribution Category UC-96

Upgraded Demonstration Vehicle Task Report

J. Bryant
K. Hardy
R. Livingston
J. Sandberg

October 15, 1981

Prepared for
U.S. Department of Energy
Through an Agreement with
National Aeronautics and Space Administration
by
Jet Propulsion Laboratory
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ABSTRACT

The Upgraded Demonstration Vehicles Task investigated vehicle/battery performance capabilities and interface problems that occurred when upgraded developmental batteries were integrated with upgraded versions of commercially available electric vehicles. Vehicles used in the testing program were the Jet Industries Electra Van 600, the Electric Vehicle Associates Change-of-Pace Wagon, the Battronic Truck Corporation Volta Pickup, and the South Coast Technology R-1 Electric. Developmental batteries used included nickel-zinc batteries from Energy Research Corp. and Yardney Electric Corp., a nickel-iron battery from Westinghouse Electric Corp., and an improved lead-acid battery from Globe-Union, Inc. Testing of the electric vehicles and upgraded batteries was performed in the complete vehicle system environment to characterize performance and identify problems unique to the vehicle/battery system. Constant speed tests and SAE J227a driving schedule range tests were performed on a chassis dynamometer. The results from these tests of the upgraded batteries and vehicles were compared to performance capabilities for the same vehicles equipped with standard batteries. Conclusions from the upgrade testing were that the developmental maturity of the vehicles and batteries was insufficient to merit deploying up to 200 upgraded vehicles for a technology demonstration program. A recommendation was made to defer the demonstration and extend the research activites.

PREFACE

Each of the vehicles discussed in this report was upgraded early in 1979 with state-of-the-art components. Testing of each vehicle with its own internal battery and developmental batteries was done between May 1979 and April 1980. Therefore, the status and/or conclusions presented herein apply only to this time frame. The performance and developmental maturity of electric vehicles and/or vehicle components now may be different than portrayed in this report.

ACKNOWLEDGMENTS

The detailed contents of this report would not have been possible without the diligent efforts of several people including R. Conover and T. Price who directed the vehicle/battery integration and test activities respectively. During the integration and testing of these vehicles and batteries, the following personnel all made significant contributions; J. Allison, B. Bonzo, D. Brown, R. Burleson, M. Crouch, R. Freeman, L. Johnson, D. Palmieri, T. Shain, and V. Wirth. Also, D. Griffin developed the wide-band watt meter system used during these tests. The authors are grateful for the contributions supplied by each of these people.

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SECTION I

INTRODUCTION

The Upgraded Demonstration Vehicle (UDV) Task was initiated in FY 79 as part of the JPL Electric and Hybrid Vehicle (EHV) Systems Research and Development Project. The task was established to support the Product Engineering (PE) effort of the Department of Energy (DOE) that was to accelerate the introduction of electric vehicles (EV) by transferring improved, upgraded technology into market demonstrations. Upgraded batteries and improved electric vehicles are important technological advancements which are needed before the EV can become a viable transportation alternative. The UDV Task, therefore, concentrated on: (1) selecting upgraded batteries, with the help of Argonne National Laboratory (ANL), from the DOE Near-Term Battery Program, (2) incorporating the selected batteries into selected EVs, and (3) testing the vehicles and batteries in a vehicle system environment to characterize performance and identify problems unique to the battery/vehicle system. Conclusions from upgrade testing, presented in this report, were that the upgraded vehicles and batteries were too unreliable to warrant the substantial number originally planned for technology demonstration. Instead, a scaled-down procurement was initiated to buy four additional vehicles (with two different types of developmental batteries) for further battery/vehicle system evaluation.

A. VEHICLE SELECTION

An early decision was made to use vehicles from the DOE Product Improved Electric Vehicle Program for the UDV Task as the vehicles were representative of the state-of-the-art in commercial EV production. Four different designs were available from the Product Improved EV Program which involved production of 2 vehicles by each of 4 contractors (hence, the Program is commonly known as the 2 x 4 Program and the vehicles as the 2 x 4 Vehicles). The 2 x 4 Vehicles consist of two commercial vehicles: the Electra Van 600 by Jet Industries and the Volta Pickup by Battronic Truck Corporation, and two passenger cars: the Change-of-Pace Wagon by Electric Vehicle Associates (EVA) and the R-1 Electric by South Coast Technology (SCT). Each vehicle is described in the following paragraphs and shown in Figure 1-1. The manufacturer's specifications for each of the 2 x 4 Vehicles are contained in Appendix A.

The Jet Industries Electra Van 600 is a conversion of a Japanese-made Fuji van. The Jet van is capable of carrying a driver and up to three passengers (or a comparable payload). The vehicle was delivered with seventeen 6-V lead-acid batteries (SGL 211GC-HC) making up a nominal 102-V battery pack that weighs 524 kg (1156 lb). The van is equipped with a series-wound dc motor, an armature chopper, and a four-speed manual transmission and has no regenerative braking capability.

The Volta Pickup by Battronic Truck Corporation is an original design that seats two and carries up to 450 kg. (1000 lb) of payload. The vehicle was supplied with a 144-V lead-acid battery pack (24 ESB EV-106 batteries) weighing 686 kg (1512 lb). An armature chopper, having regenerative braking capability, controls the series-wound dc traction motor. A 2-speed gear box allows selection of a gear ratio when the vehicle is not in motion.

The Change-of-Pace Wagon provided by (EVA) is a converted AMC Pacer Wagon that seats four. The propulsion battery supplied with the vehicle consists of a 120-V lead-acid battery pack constructed from 20 Varta P-125 batteries totalling 572 kg (1260 lb). Speed control for the separately excited dc motor is provided by armature and field choppers in conjunction with a three-speed automatic transmission (with a lock-up torque converter). The car is capable of regenerative braking.

The SCT R-1 Electric is a converted Volkswagen Rabbit 3-door hatchback and carries two passengers. The baseline (as-delivered) vehicle is powered by a 108-V battery pack consisting of eighteen 6-V lead-acid batteries (ESB XPV-23) weighing 514 kg (1134 lb). Speed control of the separately excited dc motor is accomplished by actuating contactors in the armature circuit (with a start-up resistor) in conjunction with a transistorized field chopper. The vehicle is equipped with a four-speed manual transmission and is capable of regenerative braking.

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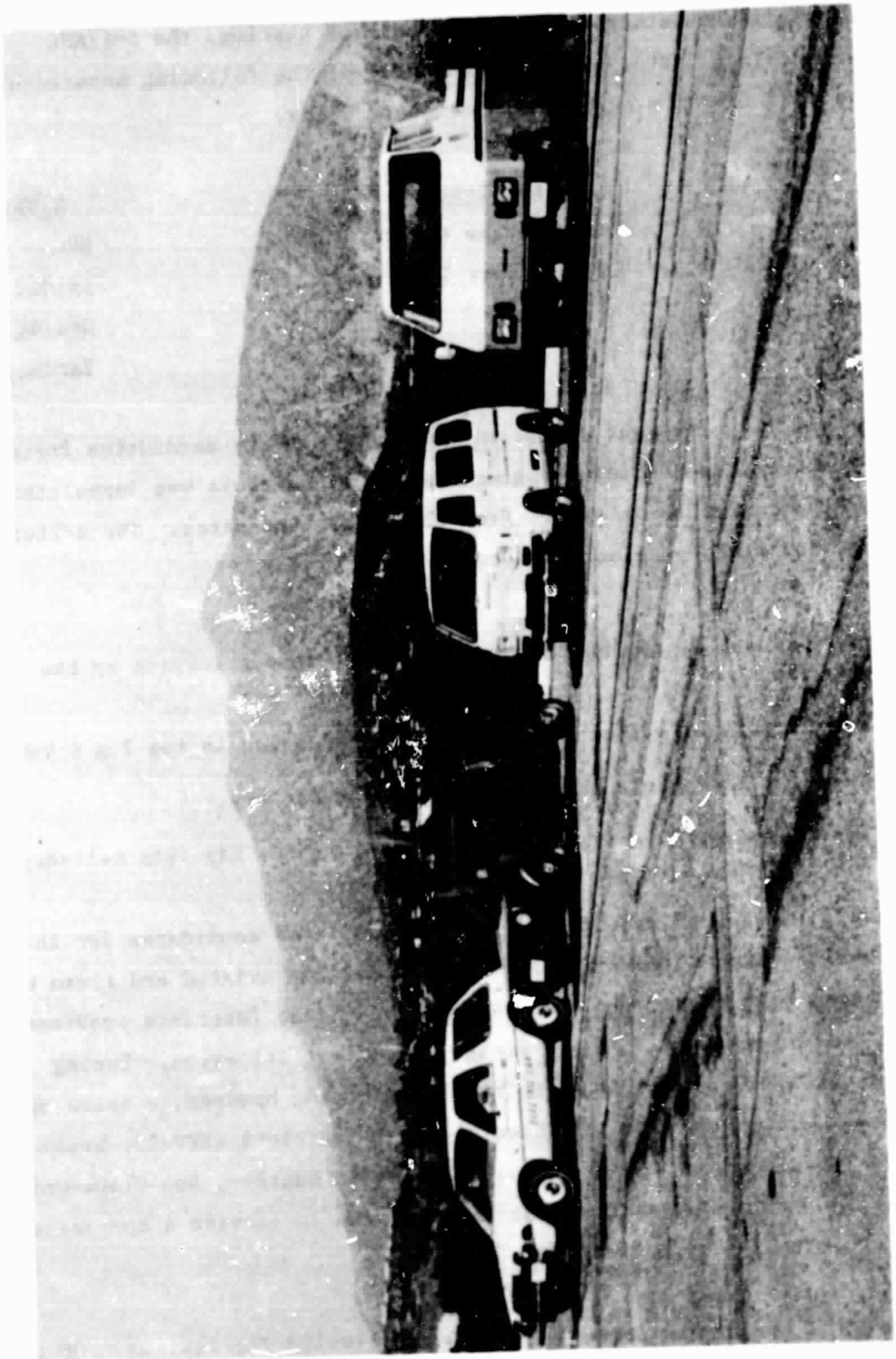

Figure 1-1. Product Improved (2 x 4) Electric Vehicles

B. BATTERY SELECTION

When candidate batteries were selected for testing, the DOE/ANL sponsored Near-Term Battery Program consisted of the following manufacturers for each of the three battery types indicated below:

Lead-Acid	Nickel-Iron	Nickel-Zinc
Exide, Inc.	Westinghouse Electric Corp.	ERC
Globe-Union, Inc.	Eagle-Picher Industries, Inc.	Exide, Inc.
Eltra Corp.		Gould, Inc.
		Yardney, Inc.

Thus, there were eight potential near-term battery candidates for the Upgraded Demonstration Vehicle Program. A set of criteria was formulated to help select batteries to be tested from the eight candidates. The criteria established for battery selection were:

(1) Willingness of the battery manufacturers to participate in the program.

(2) Suitability of battery modules for installation in the 2 x 4 Vehicles.

(3) Need for in-vehicle data on a particular battery.

(4) Likelihood of a particular battery meeting the May 1979 delivery date for testing.

Initially, lead-acid batteries were not considered candidates for this task. Some in-vehicle lead-acid battery data already existed and there was little concern that there were unknown battery/vehicle interface problems. Lead-acid batteries, then, did not satisfy the first criterion. During testing of the battery candidates initially selected, however, a spare set of lead-acid batteries, designed for Electric Test Vehicle-1 (ETV-1), became available. Because this was an improved lead-acid battery, the Globe-Union, model EV2-13 battery was added to the test program to provide a comparison with the other near-term batteries.

Two each of the nickel battery types were selected for testing. Of the two nickel-iron candidates, the second criterion excluded the Eagle-Picher battery leaving the Westinghouse battery as the only near-term nickel-iron battery available for the UDV Program. Application of the selection criteria to the nickel-zinc candidates resulted in testing ERC and Yardney.

The batteries used during testing are described briefly in the following paragraphs.

The Globe-Union lead-acid battery (EV2-13) is constructed in basically the same manner as other conventional lead-acid batteries developed by Globe-Union. However, the cells have been rotated vertically (i.e., cells were parallel to the length of the battery rather than the width) to increase the surface area and aspect ratio. The negative plate is free of antimony.

The nickel-iron battery manufactured by Westinghouse uses plates of hot-pressed, nickel-plated steel wool. The positive plate is electrochemically impregnated with nickel and the negative is pasted with ferric oxide (Fe_3O_4). This battery uses a circulating electrolyte system that pumps the potassium hydroxide (KOH) electrolyte through the cells and a heat exchanger. Circulation of the electrolyte provides the cooling needed and allows gaseous effluents to be managed during charge.

The nickel-zinc battery manufactured by ERC is based on a unique cell construction. The positive plate is manufactured from an active material composition of nickel hydroxide and conductive diluent that is rolled and pressed with a plastic binder onto a metal current collector. Zinc oxide and additives are combined and bound in the same manner to form the negative plate.

Yardney's nickel-zinc battery pack is constructed of cells using electrochemically impregnated, sintered nickel positive plates. The negative plate is bound in the same manner as the ERC cell. The separator is a three-part system using proprietary Yardney separators.

Each of the batteries were specified to provide a nominal voltage of 108 V. This terminology is somewhat vague and does not imply that the batteries have the same operating voltage under load conditions (as will be shown in a later section). In meeting this specification, the basic differences in design and electrochemical cell potential necessitated differences in the number of cells in each battery and the total battery weight. Table 1-1 summarizes these differences.

C. VEHICLE/BATTERY COMBINATIONS

Because the testing time and facilities required for the number of possible vehicle/battery combinations exceeded that which was available for the UDV program, a method for selecting and prioritizing the vehicle/battery combinations was required. Therefore, a second set of guidelines was developed for selection of the battery/vehicle combinations to be tested. These criteria were:

(1) Electrical compatibility of vehicles and batteries.

(2) Delivery schedule (availability) of the 2 x 4 Vehicles and the near-term batteries.

(3) Vehicle characteristics demonstrated in baseline testing ("as-delivered" vehicles with lead-acid batteries).

Table 1-1. Upgrade Battery Characteristics

Battery	Number of Cells in Battery	Weight kg (lb)
ERC Nickel-Zinc	66	561 (1236)
Yardney Nickel-Zinc (SCT)	72	539 (1188)
Yardney Nickel-Zinc (EVA)	80	599 (1320)
Westinghouse Nickel-Iron	90	590 (1300)[a]
Globe-Union Lead-Acid	54	490 (1080)

[a]Based on measured cell weight plus an estimated 1.13 kg per cell for the electrolyte pump, reservoir and heat exchanger.

On the basis of the first two criteria and the contract specifications for each of the 2 x 4 Vehicles, the SCT and Jet vehicles were selected as the primary test vehicles with the upgrade batteries. The remaining vehicles were assigned secondary priority. Problems with the Jet vehicle in the baseline testing resulted in the SCT vehicle becoming the sole primary vehicle. As a result of these factors, the Yardney Ni-Zn battery was the only upgrade battery tested under pulsed (armature chopper) conditions. The resulting matrix of battery/vehicle test combinations is illustrated in Table 1-2.

Table 1-2. Upgraded Demonstration Vehicle Tests

Vehicle (Baseline Battery)[a]	Baseline	Globe-Union EV2-13	Westinghouse Ni-Fe	ERC Ni-Zn	Yardney Ni-Zn
SCT (ESB XPV-23)	●	●	●	●	●
JET (SGL 211 GC-HC)	●				
EVA (Varta P-125)	●				●
BATT (ESB EV-106)	●				

[a]Defined as the battery delivered with the particular vehicle.

SECTION II

SUMMARY OF BATTERY AND VEHICLE TEST RESULTS

A. INTRODUCTION

It was intended that each battery system be installed in a separate vehicle, but this was never accomplished. Vehicle reliability problems precluded the dedication of any given battery system to any given vehicle. Also, the Westinghouse electrolyte circulation and gas effluent systems were in a rudimentary state and suffered from problems typical of initial designs. Because of the leaking electrolyte systems and the desire to match available battery systems to functional vehicles, the batteries were placed alongside the vehicles. Testing was accomplished by electrically connecting the car to each battery through an umbilical cord. Both nickel-zinc batteries were structurally sound and were capable of being installed in the vehicles.

B. BATTERY TEST RESULTS

The upgrade batteries demonstrated significant improvements in energy density relative to the baseline batteries. Deficiencies in other aspects of overall performance, however, must be corrected before successful integration of the upgrade batteries into a long term demonstration program. The lead-acid battery had relatively poor performance from one or more modules within the battery. Both nickel-zinc batteries exhibited poor cycle life. Further development in packaging the electrolyte circulation system and handling the volume of hydrogen generated at the relatively high charge rate is required for the nickel-iron battery.

The upgrade batteries posed no problems in terms of electrical compatibility with the vehicles other than the higher system voltage associated with the nickel batteries. Both attempts to operate the EVA Pacer on the Yardney battery precipitated a failure in the EVA's controller. Also, there was concern over possible safety problems. The close proximity of lead-acid battery electrolyte (sulfuric acid) and nickel battery electrolyte (potassium hydroxide) presented a difficult handling problem, because of the leaks in the nickel-iron battery. Also the copious quantities of hydrogen liberated by the nickel-iron battery during charge mandated that all gaseous effluents be diluted and vented outdoors to prevent hydrogen buildup to dangerous levels. JPL was probably overly cautious in handling these developmental batteries. Future refinements of charging procedures may alleviate many of these safety problems.

Energy density improvements were heavily dependent on the type of test being performed; that is, the batteries varied in their ability to maintain the same energy capacity at different power levels. The Yardney and Westinghouse nickel batteries were exceptional as illustrated in Figure 2-1 which shows the energy densities exhibited by the upgrade batteries and by the baseline lead-acid battery in the SCT vehicle during constant speed range tests. This figure shows the average energy density delivered by the batteries being discharged at the average power levels shown.

There are other battery performance characteristics that must be considered in the overall assessment. These include the voltage discharge characteristics, charge/discharge efficiency, and recharge requirements. Because the efficiency of many vehicle components is sensitive to current, battery voltage characteristics are an important parameter. Although all the upgrade batteries were specified as 108 V, the voltage under load varied substantially from this "nominal" voltage, as shown in Figures 2-2 and 2-3. These figures show the plots of voltage as a function of ampere-hours (Ah) discharged and illustrate the ability of the upgrade batteries in most cases to maintain a higher voltage than the baseline lead-acid battery.

The importance of charge efficiency lies in the energy economy of the vehicle/battery system. The batteries varied widely in this respect, partly because of the uncertainties associated with charging the developmental batteries, but also because of the inherent characteristics of the battery construction. The lead-acid batteries performed consistently throughout the testing program, exhibiting Ah efficiencies of 80-85% and watt-hour (Wh) efficiencies of 65-70%. ERC's nickel-zinc battery was equipped with a state-of-charge meter that controlled charge termination. Operational

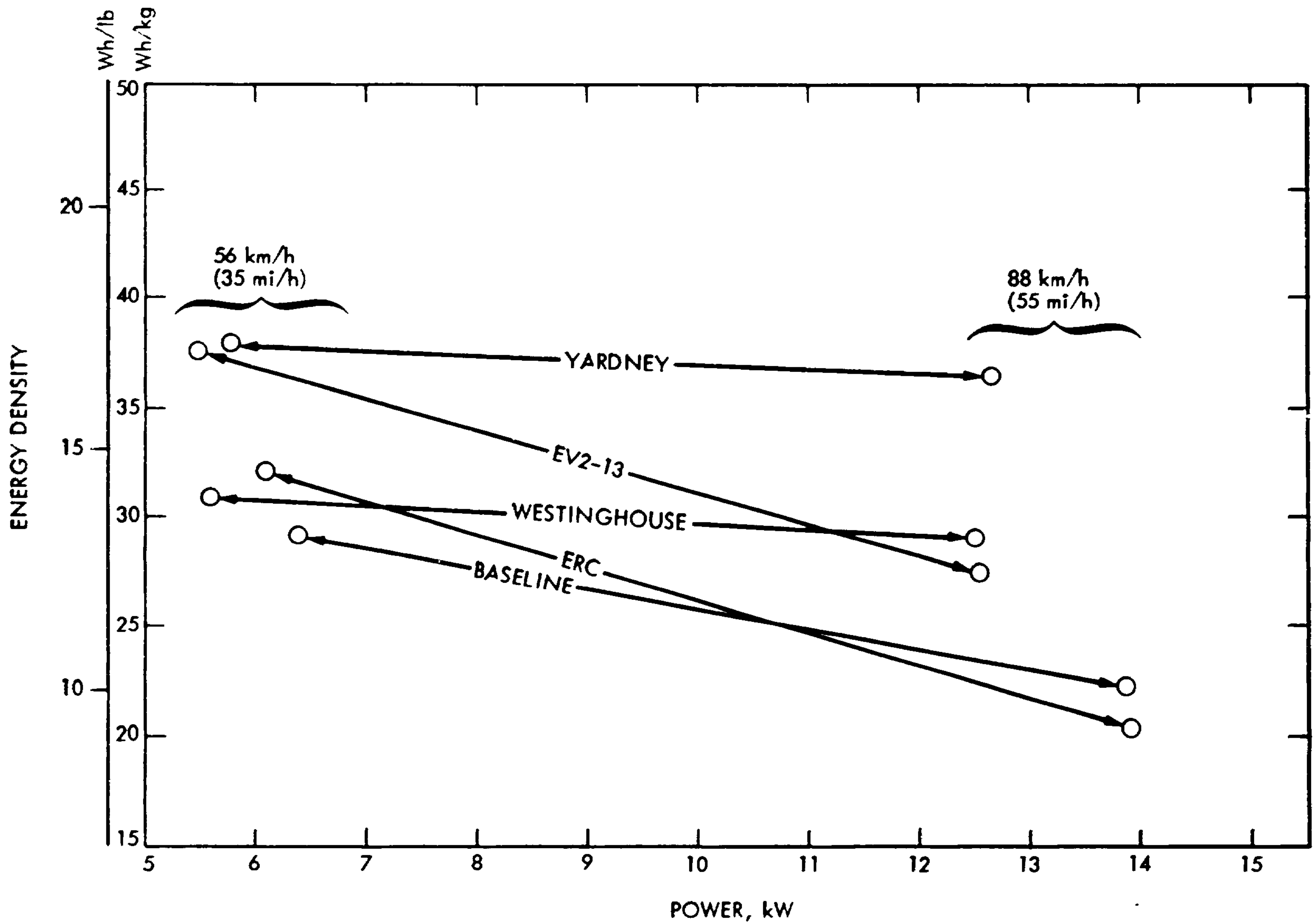

Figure 2-1. Energy Density Comparison of the Upgrade Batteries as a Function of Power (SCT Data)
Note: Interconnecting lines do not imply a linear relationship

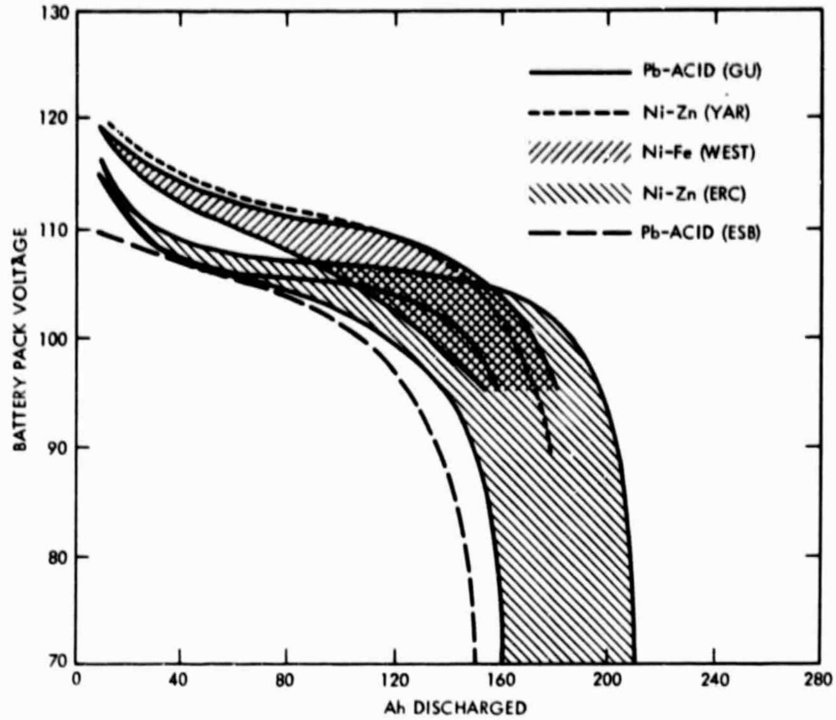

Figure 2-2. Voltage Discharge Characteristics During Low Power Tests (56 km/h)

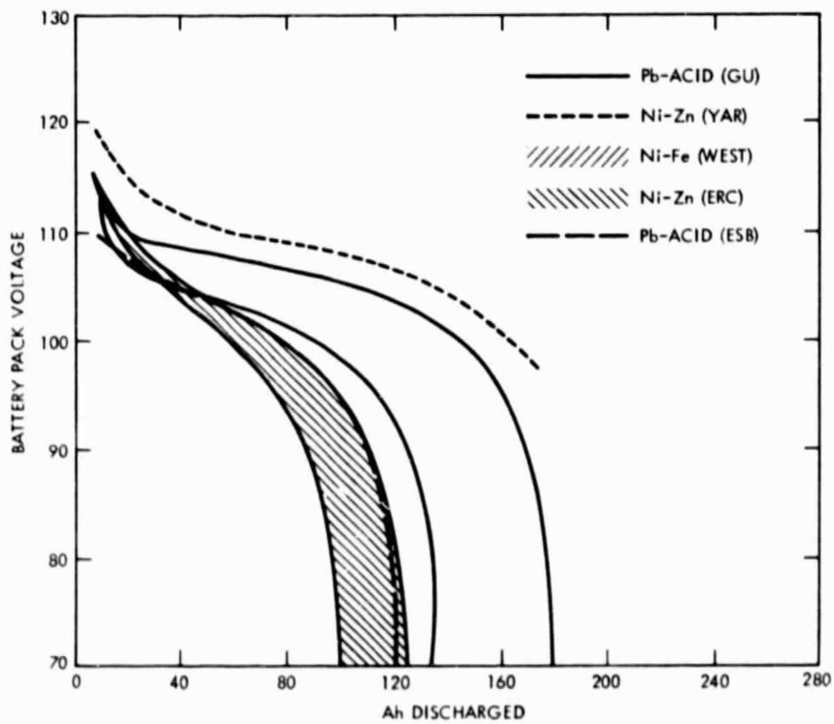

Figure 2-3. Voltage Discharge Characteristics During High Power Tests (88 km/h)

uncertainty and inaccuracy of this meter resulted in recharge efficiencies (Ah) that varied from 50 to 90%. The Yardney nickel-zinc battery used a set charge procedure that resulted in Ah efficiencies of 92-93%. The Westinghouse nickel-iron battery exhibited charge/discharge Ah efficiencies ranging from 65-70%, primarily because of the overcharge requirement specified by the manufacturer. Unfortunately, instrumentation limitations precluded the measurement of recharge energy. Charging procedures that optimize battery capacity, life, and recharge efficiency will reduce the magnitude of overcharge. In other words, all of the recharge data presented herein reflects charge procedures designed to assure maximum battery capacity (i.e., vehicle range).

C. VEHICLE TEST RESULTS

The 2 x 4 Vehicles varied widely in efficiency and engineering detail, but were designed for substantially different purposes. Both the SCT and EVA vehicles were designed as passenger vehicles. The EVA vehicle, however, is capable of carrying four passengers, twice that of the SCT. The Jet and Battronic vehicles are intended for commercial applications, but the Battronic vehicle can carry a 295 kg (650 lb) payload exclusive of the 68 kg (150 lb) driver allowance, compared to a 204 kg (450 lb) payload capacity in the Jet van under the same conditions. Thus, direct comparison of vehicle performance would be of little value. With this in mind, the vehicle ranges observed during constant speed tests of the 2 x 4 Vehicles are shown in Figure 2-4.

Other parameters of vehicle performance, such as reliability, must be considered when assessing the test results presented in this report. The SCT vehicle had problems with the propulsion system (i.e., motor failure and intermittent controller failures) which required correction soon after delivery. Subsequent to the initial failures, the SCT operated reliably throughout the rest of the test program. The Jet van experienced motor and controller overheating which eliminated the possibility of using the vehicle as a test bed for the upgrade batteries. The EVA vehicle exhibited limited problems with the controller which required the manufacturer's attention (two of the failures occurred during operation at higher than rated voltages). The Battronic vehicle operated without failure throughout its limited testing program at JPL.

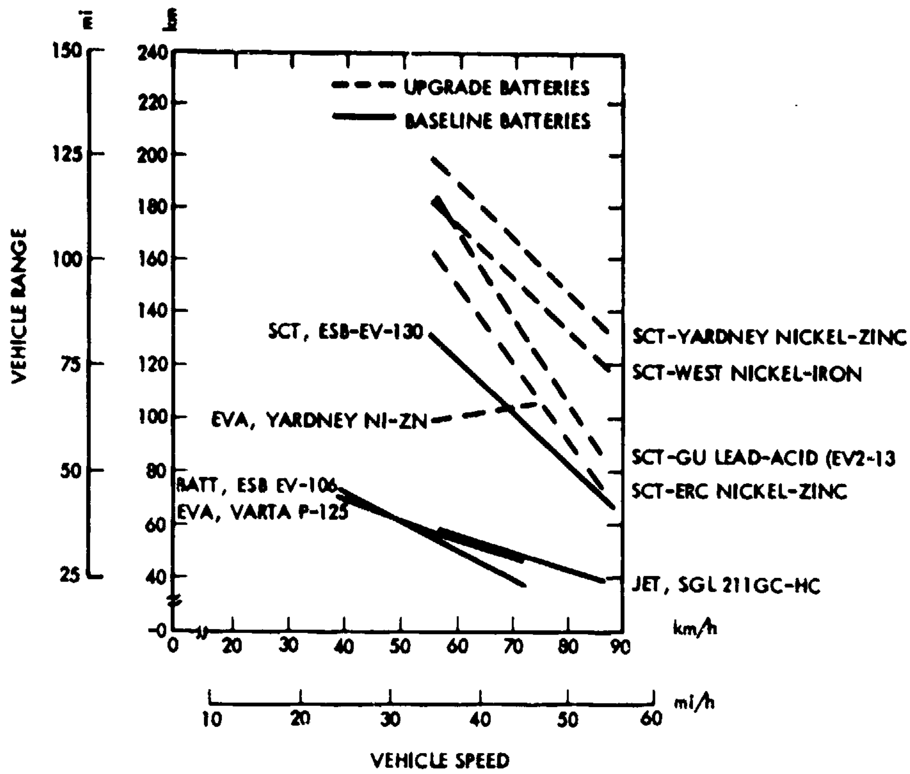

Figure 2-4. Electric Vehicle Range Comparison with the Baseline and Upgrade Batteries

An additional problem common to each vehicle was the lack of a battery charger or an initial lack of reliability when a charger was provided. Because of this problem, all battery charging was done with a laboratory type power supply during performance testing.

The above problems have been presented to enhance reliability of future EVs. Although the problems may appear numerous, these vehicles still exhibited a considerable improvement compared to vehicles produced only a few years earlier. Most failures were encountered early in the test program and the cars have been relatively dependable since that time.

SECTION III

TEST PROCEDURES

All vehicle/battery tests were conducted on a chassis dynamometer. Track tests were used to establish road load for dynamometer settings. Because there were only small differences in battery weight, the unique dynamometer settings for each vehicle were held constant regardless of the battery type to enhance the comparisons of the test results.

The track tests were performed on a runway at Edwards Air Force Base. During these tests, the vehicles were instrumented with a fifth wheel and strip chart recorders. Environmental conditions were also monitored to insure that the wind velocity and other conditions were within the guidelines set by the JPL Field Test Procedure (Ref. 1).

The dynamometer tests were conducted at JPL's Automotive Research Facility. Range tests included constant speeds and the SAE J227a driving schedules (Ref. 2). The vehicles were instrumented to obtain the voltage, current, temperature, power, amperage[1], and energy at various locations in the propulsion system. Figures 3-1 through 3-8 are pictures of the 2 x 4 Vehicles and schematics of their respective propulsion systems showing the locations of the sensors. These sensors are part of the power/energy measurement system which was designed and fabricated at JPL (Ref. 3).

The following discussion briefly outlines the test procedures employed in the road and dynamometer tests. Additional information on the test methods can be found in the individual "baseline" test reports for the individual vehicles (Refs. 4, 5, 6, 7). A comprehensive description of JPL test procedures for electric vehicles is planned for publication in 1981 (Ref. 8).

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[1]In the context of this report, amperage refers to an Ah measurement.

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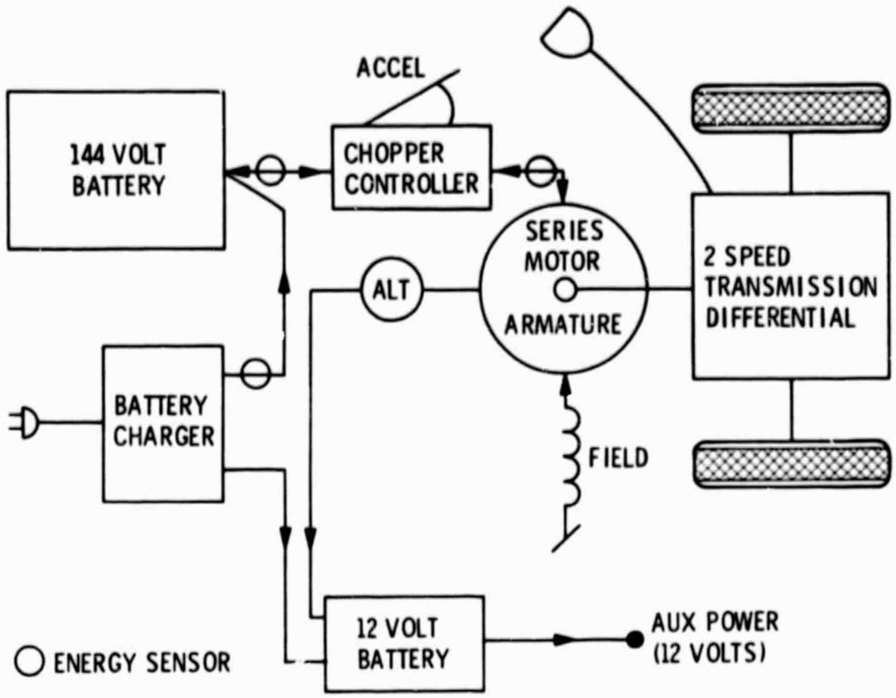

Figure 3-1. Battronic Energy Sensor Locations

Figure 3-2. Battronic Volta Pickup

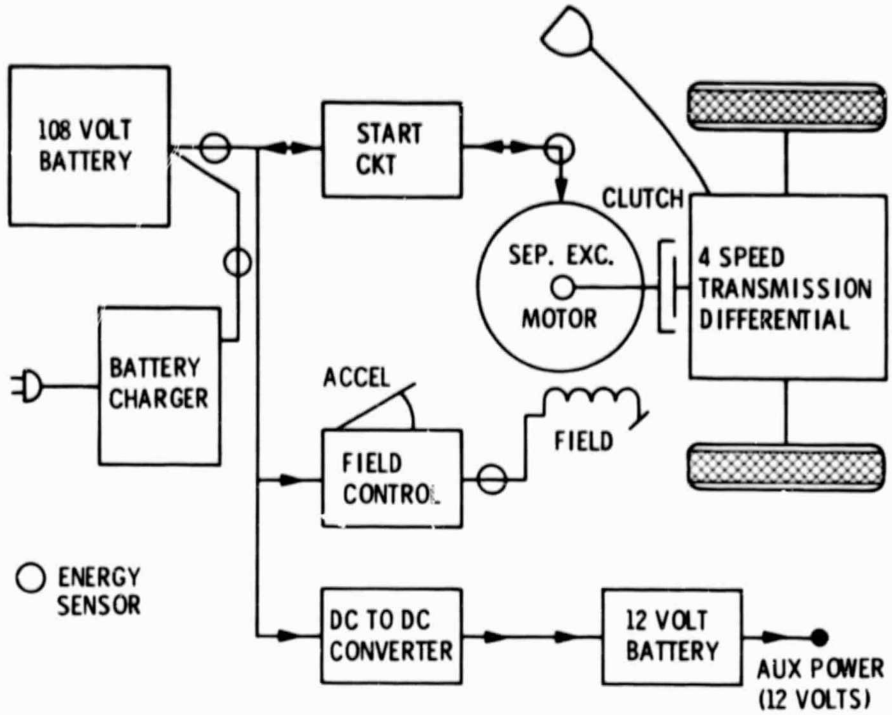

Figure 3-3. EVA Energy Sensor Locations

Figure 3-4. EVA Change-of-Pace Wagon

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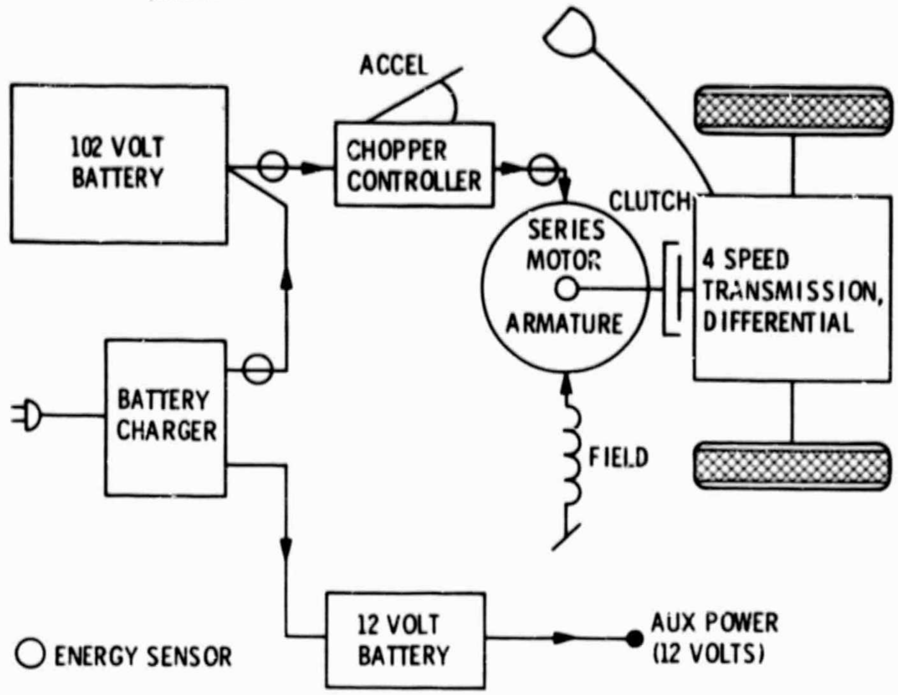

Figure 3-5. JET Energy Sensor Locations

Figure 3-6. Jet Industries Electra Van 600

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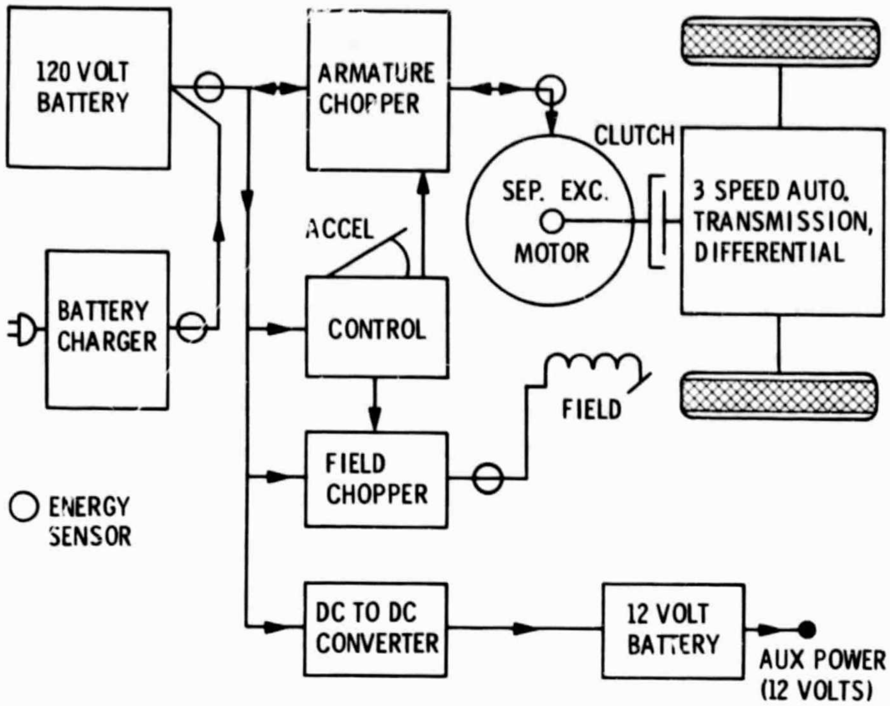


Figure 3-7. SCT Energy Sensor Locations

Figure 3-8. SCT R-1 Electric

A. ROAD TESTS

1. Coast-Down Tests

Vehicles were driven or towed on the runway for a minimum of 19 km (12 mi) to warm-up the drivetrain and tires before testing. Because of the limited length of the uniform portion of the runway, 1200 m (4000 ft), coast-downs were done in two segments to provide level road-load data from 88 km/h (55 mi/h) to 16 km/h (10 mi/h). Runway length limitations also necessitated using a tow vehicle to accelerate the EV up to the desired speed before releasing it to initiate the coast-down process. This procedure was repeated until 10 acceptable pairs of opposite direction runs were completed for each of the high speed and low speed coast segments. All coast-downs, except for the EVA Change-of-Pace and the Battronics truck, were done with transmissions in neutral and the clutch disengaged. The automatic transmission of the EVA car was placed in neutral, and the clutchless Battronic transmission was forced to a position where neither of the two torque paths were engaged. Analysis of the track coast data at 80 km/h (50 mph) and 24 km/h (15 mph) provided the basis for the dynamometer adjustments.

2. Best Effort Acceleration Tests

Though the intent was to test each 2 x 4 Vehicle for maximum acceleration in its baseline configuration, time constraints precluded all but the SCT vehicle from being tested. This vehicle was accelerated as fast as possible in both directions on the test track using shift points specified by SCT. Between acceleration runs, the vehicle was driven the entire length of the track and back at 32-48 km/h (20-30 mi/h). This procedure of using two best effort accelerations followed by a low speed cruise was repeated until the baseline battery terminal voltage was less than 70 V (1.3 V per cell). In this way, the acceleration capability was determined at various depths of discharge (DoD) from 0% to approximately 100%. The DoD is unique to each particular discharge rate, where 100% DoD is empirically determined as that point where battery voltage falls below 70 V. All acceleration tests on the track were performed between 21^{o} and 29^{o}C (69^{o} to 85^{o}F).

B. DYNAMOMETER TESTS

Vehicle range tests were all conducted on a chassis dynamometer. Preceding each range test the test vehicle was allowed to "soak" at 21°C (70°F) until the on-board batteries and the vehicle drivetrain stabilized near this temperature. All vehicle range tests which used lead-acid batteries had an initial (start of test) temperature of 21 $\pm$ 3°C (70 $\pm$ 5°F), and the nickel batteries had a variety of initial temperatures (see paragraph C). Within one hour before testing, the dynamometer was warmed up with a different vehicle and then calibrated to the unique adjustments needed for each test vehicle as determined previously from coast-down data. Range tests consisted of a minimum of two repeats of each specific type of J227a driving schedule or constant speed test.

1. Constant Speed Range Tests

The vehicle was accelerated as quickly as possible to the given cruise speed without vehicle warm-up. Tests were run at cruise speeds of 40, 56, 72 and 88 km/h (25, 35, 45 and 55 mi/h), with 56 km/h and 88 km/h being the primary test speeds for those vehicles capable of sustaining 88 km/h. Speed was maintained within 5% until the battery voltage fell below the value specified by the battery manufacturer or reached 1.3 V per cell (JPL specified termination criteria for lead-acid battery tests). The vehicle was then brought quickly to a stop.

2. Driving Schedule Range Tests

These tests consisted of driving the prescribed schedule until the vehicles were unable to meet the cycle acceleration requirements or until the minimum battery voltage criterion was attained. The driving schedules were JPL standardized versions of the SAE J227a driving schedules in which details of acceleration, coast, and braking were defined to simulate normal driving characteristics. Linear ramps are inferred from the SAE specifications of speeds reached at given times (Ref. 2). The accelerations, used by JPL, are an average of the acceleration profiles used in the Federal Test Procedure (FTP) (i.e., EPA Urban Driving Cycle). The resulting profiles were normalized to the appropriate time constraints of the J227a procedure and closely approximate a constant power acceleration. The cruise is a constant speed operation for the time specified by the SAE. The coast rate is similar to that of a conventional vehicle with an automatic transmission. The coast time specified by SAE has been reduced by three seconds in the "D" cycle, and braking extended by an equal increment. These modifications allow the braking rate to stay below the 5.3 km/h/s (3.3 mi/h/s) rate found in the FTP. The authors of the SAE J227a procedure clearly indicate that the driving schedules were not intended to simulate how vehicles are typically driven. Likewise, JPL's standardization of these profiles, although using a "how people drive" rationale, was not intended to provide any emulation of typical driving patterns. Standardization was done solely to minimize the extensive subjectivity found in the basic J227a procedure. Without this standardization, battery comparisons based on the driving schedules would be difficult. In other words, different interpretations of the driving schedules could have a larger impact on vehicle range than would differences in the batteries reported herein.

In summary, with the exception of the split between coast and brake in the "D" cycle, the J227a specifications of time vs. speed remain as defined by the SAE. Details of the JPL standardized cycles can be found in Appendix B. The vehicles that participated in the 2 x 4 Vehicle testing program were evaluated on the J227a "B" and "D" cycles (or J227a "C" if the "D" cycle could not be performed). The speed-time profiles of the "B" and "D" cycles are shown in Figure 3-9.

C. BATTERY CHARGING AND CONDITIONING

1. Lead-Acid Batteries

Two major factors contributed to JPL's decision to use external equipment for charging the on-board battery packs:

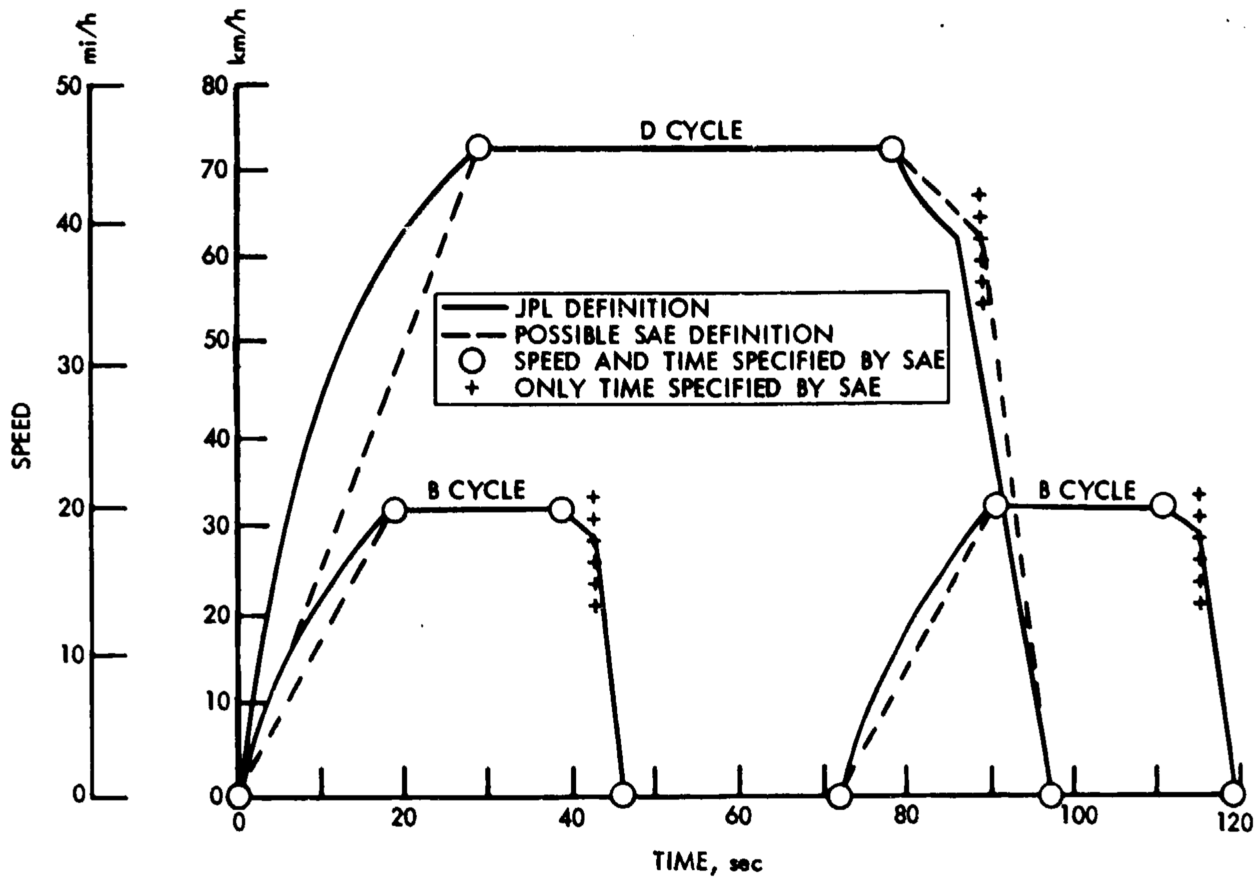


Figure 3-9. JPL Standardized J227a "B" and "D" Driving Schedules

(1) The on-board chargers of the first vehicles tested (SCT-VW and the EVA-Pacer) were of poor design and either failed to provide a reasonable charge or failed altogether. Lester Co. chargers, provided in the rest of the vehicles, suffered from early reliability problems and were not functional during testing. Subsequent to vehicle testing, the Lester Co. chargers have operated reliably.

(2) To minimize the number of variables in making battery comparisons, each battery should be charged by the same generic technique. This could only be achieved with an off-board charger.

Except for the Battronic truck, all of the vehicles were equipped with new lead-acid battery packs. Therefore, each set of batteries was "conditioned" by conducting 10 to 15 deep discharge/charge cycles using an external load. Although the conditioning process was needed to bring the various battery packs up to their rated capacity, the process also served other important purposes. Weak battery modules were identified and replaced before any vehicle tests were initiated. Also, the basic charging procedure was refined to satisfy the unique needs of each battery pack.

To expedite EV testing, JPL performed "quasi-equalization" charges instead of the equalization charge specified by the SAE-J227a test procedure. This change reduced the charge time and the subsequent "soak" time needed to allow the battery pack to cool to the JPL-imposed temperature of $21^{\circ} \pm 3^{\circ}C$. The use of the "quasi-equalization" charge permitted this process to be automated. The characteristics of JPL's lead-acid charge procedure are as follows:

(1) Charge at a constant current of 25 A until the battery pack reaches the clamping voltage empirically determined during "conditioning".

(2) Once the temperature compensated clamping voltage is achieved, a timer is initiated and voltage is held constant (except for the compensation for electrolyte temperature) while current tapers to a low value.

(3) Continue charging for the 6-h duration of the timer (6.5 h for Globe-Union batteries) and then terminate battery charge.

Clamping voltage is defined as that voltage which is required, at the 5-h point of the timed charge, to keep charging current between 3 A and 5 A. This nominal 4-A finish current was selected to minimize electrolyte stagnation by inducing agitation through electrolyte gassing. As previously indicated, this necessitated a unique clamping voltage for each battery pack. Table 3-1 lists the clamping voltages for each battery system and Figure 3-10 represents a typical charge profile. The time when the clamping voltage was achieved and

Table 3-1. Lead-Acid Battery Clamping Voltage

Battery Pack	No. of Batteries	Clamping Voltage[a]	Equivalent Cell Voltage
ESB EV-106	24	192.0	2.67
ESB XPV-23	18	145.8	2.70
G-U EV2-13	18	136.8	2.53
SGL 211GC-HC	17	137.7	2.70
Varta P-125	20	156.0	2.60

[a]Temperature compensation = -0.004 V/^{o}F/cell, 80^{o}F reference.

the timed taper charge was initiated is the point where the amperage (Ah) previously discharged has been 95% replaced. The balance, or timed portion, of the charge primarily reflects overcharge and results in a relatively constant quantity of amperage being returned during the overcharge. As such, recharge efficiency is partially a function of the preceding discharge. During the testing described here, recharge efficiency (Ah) was between 80 and 85%. As seen by the increased battery heating (Figure 3-10) the most inefficient charging occurs during the extensive (timed) taper charge. This increased heating is a product of the test process and would not be typical of a properly designed charger under normal operation.

2. Nickel Batteries

Each of the three nickel batteries in the upgrade program was charged according to specifications supplied by each battery manufacturer. The chargers for each respective battery was also supplied by each manufacter as part of the battery system. All of these chargers were "laboratory" type devices that were never intended to be optimized for vehicle use. Because

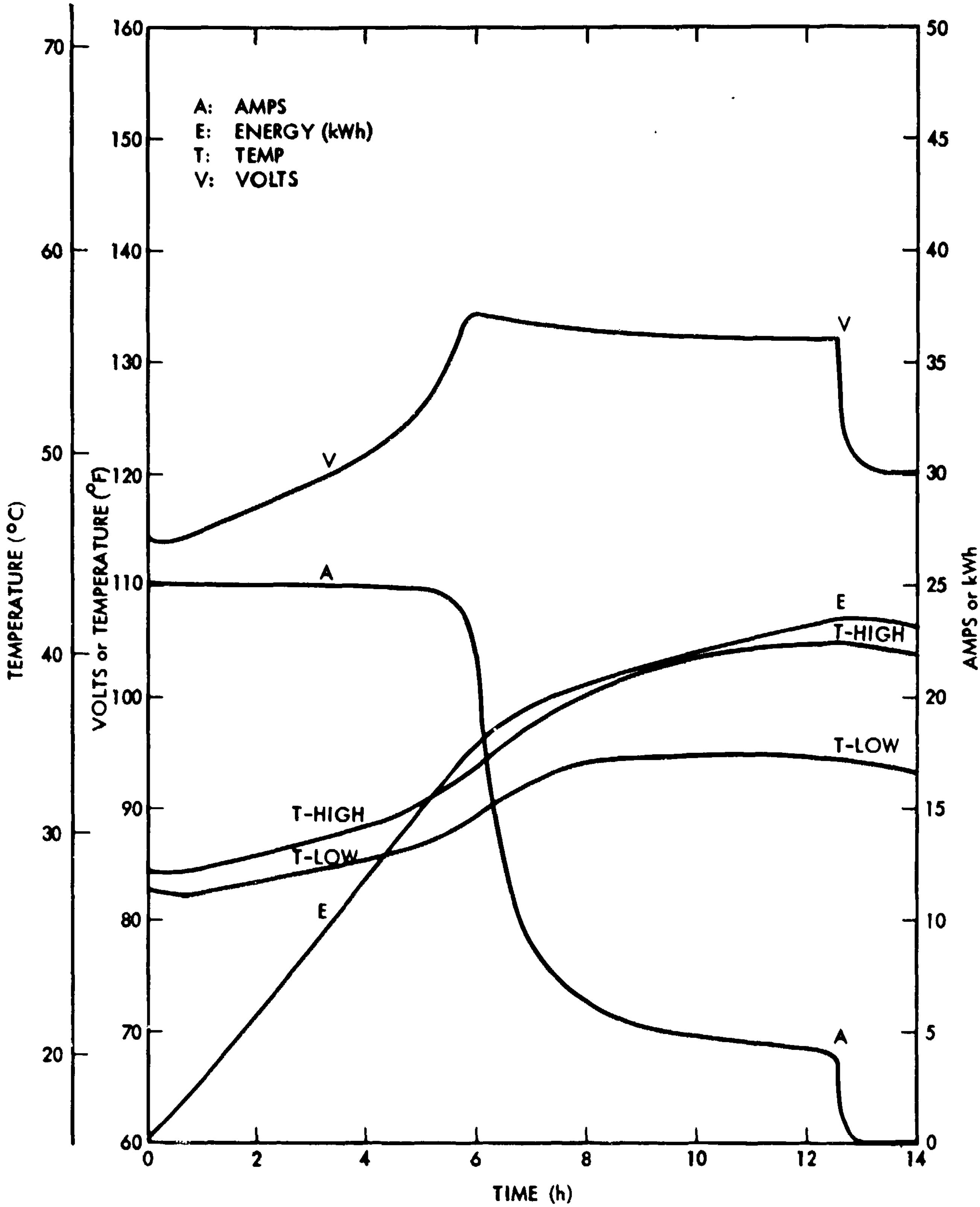


Figure 3-10. Typical Lead-Acid Battery Charge (Globe EV2-13)

these chargers were only used as tools to aid in the evaluation of the battery and battery/vehicle interface, there was no attempt to characterize the performance of the charger itself. Unlike the lead-acid battery tests, all vehicle tests with nickel batteries were performed with no "soak" period after charge. As such, battery temperatures at test initiation were usually much higher than the 21°C imposed on the lead-acid batteries. This higher temperature, up to 38°C (100°F) is not necessarily a benefit to the nickel battery capacity. The lack of a soak period was beneficial because self-discharge, which is most severe when nickel batteries are fully charged, was precluded by starting a test immediately after recharge. The effects of battery temperature and self-discharge were not quantified.

The charger supplied with the ERC Ni-Zn battery consisted of a transformer and a variac followed by a full wave rectifier. This charger operated from a 230 VAC, 30 A circuit. Battery state-of-charge (SoC) was supplied by a 0.5 Ah nickel-hydrogen pilot cell. This cell was coupled to the Ni-Zn propulsion battery through a shunt and provided SoC indication on a pressure gauge attached to the pilot cell. A pressure switch connected to the pilot cell was used to terminate battery charging. Uncertainty of the correlation of the pressure gauge (and pressure switch) to recharge amperage necessitated periodic consultation with ERC for adjustment and calibration. Charging current was held at a nominal 25 A by intermittently adjusting the variac until the pressure switch terminated the charge. Recharge time took anywhere from 8 to 16 h depending on the depth of the previous discharge and the calibration of the SoC indicator. The ERC battery was force cooled with several fans to minimize the temperature rise above the 21°C (70°F) ambient.

Three series connected regulated power supplies comprised the charger for the Yardney Ni-Zn battery. Each power supply was powered by a separate 115 VAC, 30 A circuit. The SoC information was provided by a commercial coulombmeter connected to the Ni-Zn propulsion battery via a shunt. Charging was terminated by a meter relay within the SoC gauge. The charging instructions for the Yardney battery were the most sophisticated of all the nickel batteries.

Even this charging technique, however, required minor adjustments to overcome a continuing loss of battery capacity during the initial 3 vehicle/battery tests. The resulting charge scheme started with a constant charge current of 18 A and continued until the battery clamping voltage of 135.4 V (2.05 V/cell) was achieved, after which current was allowed to taper. Charge was terminated automatically by the coulombmeter when recharge exceeded the previous discharge by 12%. Because of the good reliability and repeatability of the Yardney charger, JPL segmented the charge to minimize after-hour manpower. A normal charge was initiated at the end of each working day. This charge terminated automatically 12 to 14 h later. Before test initiation (discharge), additional charge was added, based on the length of stand (soak) from charge termination, to compensate for self-discharge. Table 3-2 defines the amperage needed to compensate for self-discharge. Use of these charge algorithms resulted in a very repeatable battery capacity with no apparent degradation over the limited cycle life at JPL (22 cycles). Interestingly, the Yardney battery was never charged to its design capacity. To avoid the deleterious effects of battery charging above approximately 85% SoC, Yardney rated the battery at 80% of the design (maximum) capacity. As such, the battery was always operated in the bottom 80% of the design capacity, where 80% design capacity is equal to the 100% rated capacity (250 Ah) discussed later in this report.

Westinghouse's nickel-iron battery was charged at much faster rates than any other battery in the upgrade program. A constant charge current of 70 A

Table 3-2. Self Discharge Compensation

Stand Time (days)	Topping Charge (Ah)
$<$ 0.5	2
0.5 to 1.0	4
1.0 to 8.0	6 per day

was specified by the manufacturer because of the poor charge acceptance of the negative electrode at lower currents. Overcharging ranged from 20% to 50% by manually stopping the charge. A 33% overcharge became the nominal value used at the finish of this battery's testing. At the direction of Westinghouse, several other overcharge values were tried during the earlier testing. To satisfy the high charging current, Westinghouse supplied a regulated power supply which operated on a 460 VAC, 50 A, 3 phase circuit. Westinghouse also supplied an electrolyte circulation system and a liquid/liquid heat exchanger to provide thermal management during charging. Tap water provided cooling for the electrolyte. During charging a pump was activated (see Figure 3-11) which drew electrolyte from a reservoir and forced it through the heat exchanger and then the 90 cell string before it emptied back into the closed reservoir. Electrolyte pumping also flushed gaseous accumulations from each cell. All gaseous effluents were expelled through a water bubbler and then vented outdoors for safety reasons.

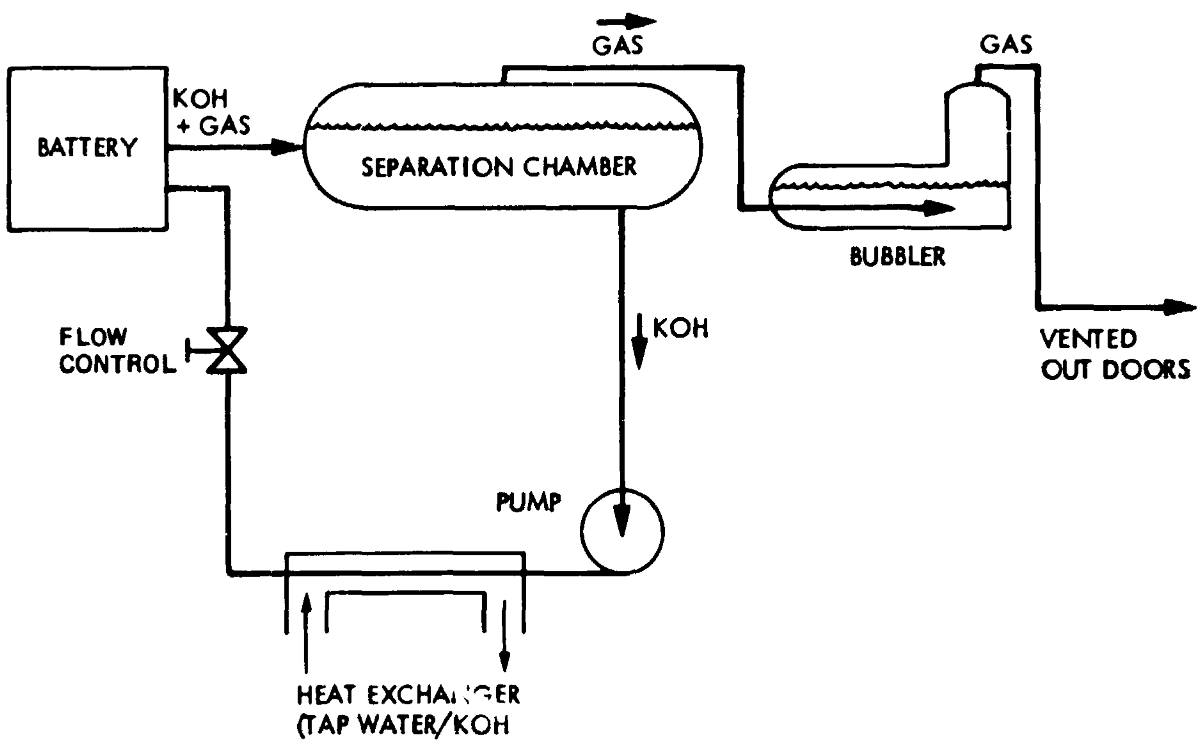


Figure 3-11. Westinghouse Electrolyte Circulation System

SECTION IV

VEHICLE CHARACTERIZATION

This section addresses the energy performance of the overall vehicle with particular attention to the performance of the electrical portion of the drivetrain. In-situ measurements of mechanical losses are difficult and expensive to implement. Because mechanical loss measurement and analysis is more cost-effective on a component test stand, no attempt was made to include these measurements as part of the battery/vehicle tests. On the other hand, the instrumentation needed to characterize the motor and controller, in addition to the battery, was relatively minor.

Because of the complexity of doing a complete vehicle analysis under each test condition, it was necessary to minimize the effects of as many variables as possible. For this reason, only certain tests were examined. The information presented here is based only on those tests performed on the dynamometer and with each vehicle's baseline lead-acid battery. Data from tests performed at the Edwards AFB test station (road-load determination) were used to characterize all mechanical (transmission to tires) and aerodynamic losses.

Several factors influenced the degree to which the vehicles could be characterized. The Upgraded Demonstration Vehicles Task was directed at vehicle testing and evaluation of improved electric vehicle batteries. Vehicle component performance investigation was not the primary objective of the testing program and the vehicles were not instrumented to yield detailed information concerning all of the individual components. The energy sensor locations in the 2 x 4 Vehicles, which were presented as Figures 3-2, 3-4, 3-6, and 3-8, provided enough information to separate the batteries, controllers, and mechanical drivetrains (motor to wheels), The battery characteristics are presented in Section V; this section deals primarily with the behavior of the controllers and drivetrains of the 2 x 4 Vehicles as derived from the dynamometer test results. The energy use characteristics of the 2 x 4 Vehicles were also investigated to determine the power and energy requirements for each of the vehicles and the energy consumption versus driving mode in the driving schedule tests. The following discussion begins with the vehicle energy use characteristics, followed by the component behavior.

A. BATTERY DISCHARGE ENERGY USE CHARACTERISTICS

1. Battery Discharge Energy Consumption versus Driving Mode

Figures 4-1 to 4-4 show the battery energy splits for the four vehicles over each of the JPL Standardized SAE J227a driving schedules. These figures present the battery energy used in each of the modes encountered in performing the driving schedules, i.e., acceleration, cruise, deceleration (coast and brake) and idle. The energy splits of Figures 4-1 to 4-4 were each obtained from a single test; that is, multiple tests were not averaged. However, the energy splits were derived by averaging all the cycles within the appropriate individual test. Therefore, the effects of vehicle warm-up (primarily tire warm-up) on battery power requirements were averaged over an entire test. Use of only a single test for this analysis has little effect on the results presented here. Because repeat tests of these vehicles in the baseline configuration generally resulted in energy economies (i.e., Wh/km or Wh/cycle) within 2% of the typical tests used here, it was thought that the extra effort in averaging all similar tests was not worth the benefits that could be derived.

a. <u>Battronic Truck Energy Splits</u>. As shown in Figure 4-1, most of the battery energy for the Battronic truck was consumed during acceleration. Considering the truck's heavy weight, the quantity of inertial energy consumption is not surprising, nor is the high percentage for the cruise mode. Poor motor and controller efficiency (discussed later) along with high road-load power requirements were the main constituents of the relatively high percentage of energy needed in the cruise mode. Also contributing to the high motive energy requirements was the use of an inefficient system (an alternator), to charge the accessory battery (see motor efficiency discussion).

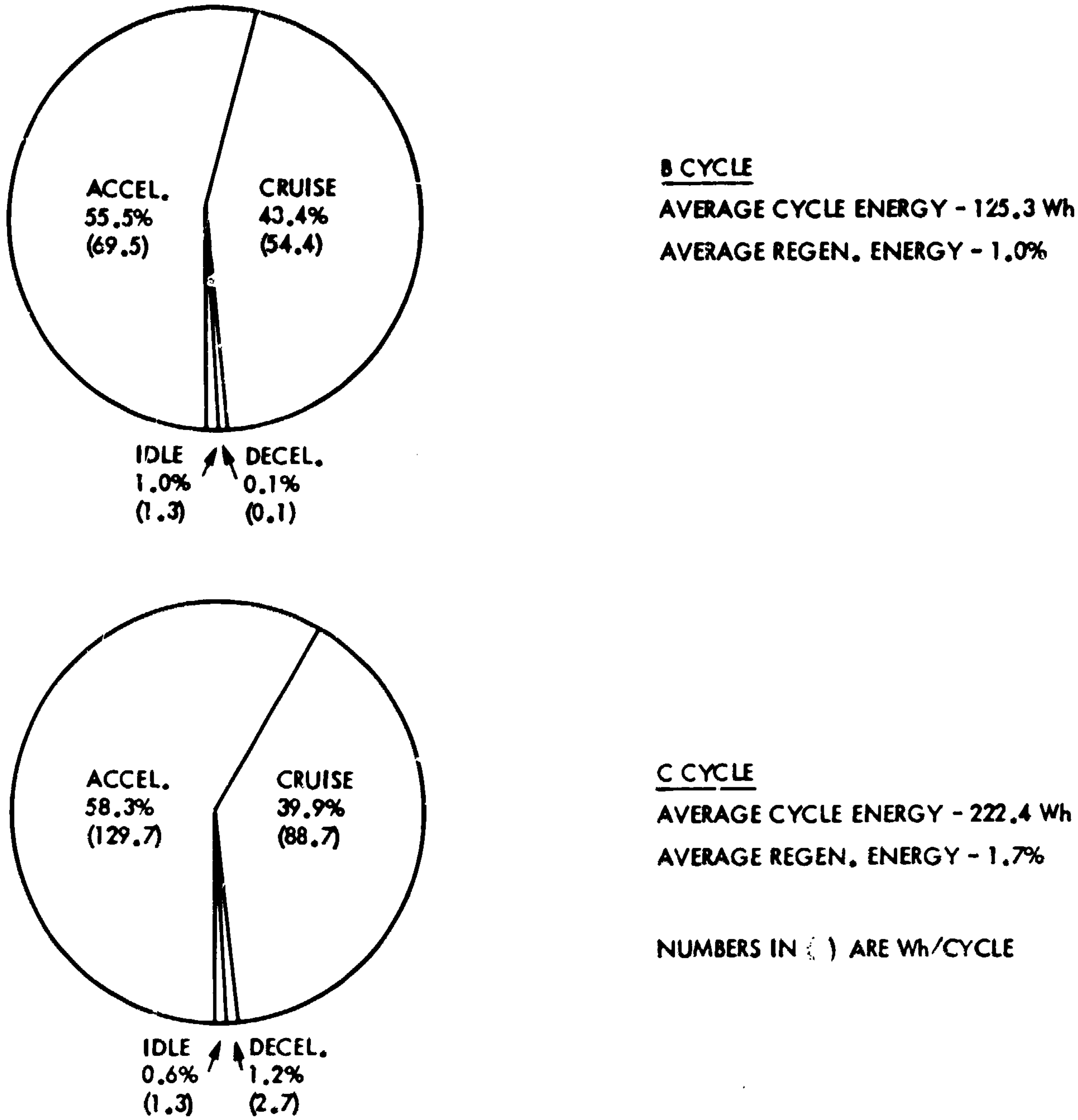
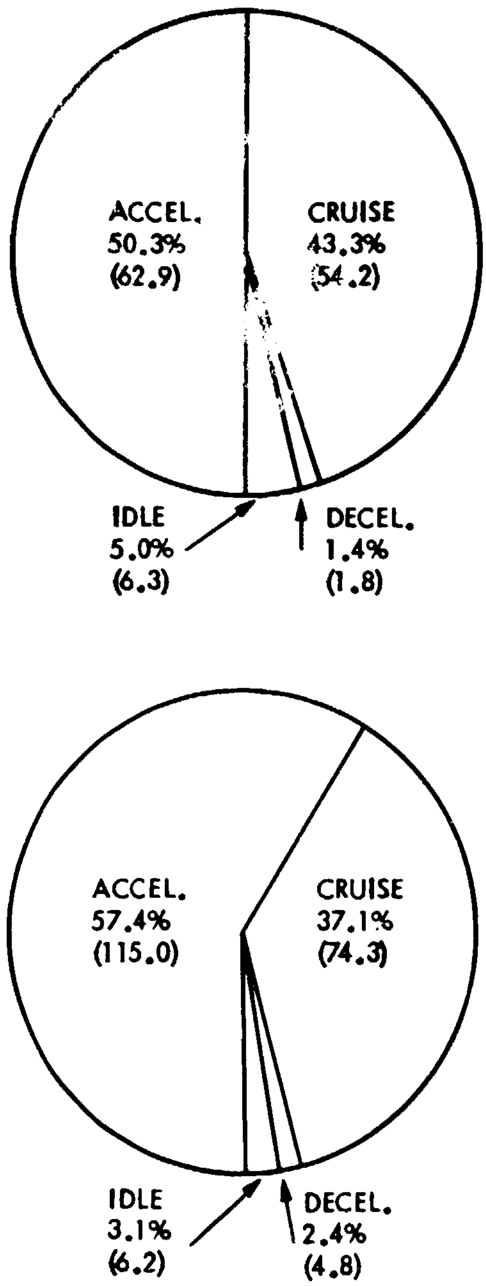


Figure 4-1. Energy Splits for the Battronic Volta Pickup Truck



B CYCLE

AVERAGE CYCLE ENERGY - 125.1

AVERAGE REGEN. ENERGY - 0.0%

C CYCLE

AVERAGE CYCLE ENERGY - 200.4 Wh

AVERAGE REGEN. ENERGY - 0.0%

NUMBERS IN ( ) ARE Wh/CYCLE

Figure 4-2. Energy Splits for the Electric Vehicle Associates Change-of-Pace Wagon

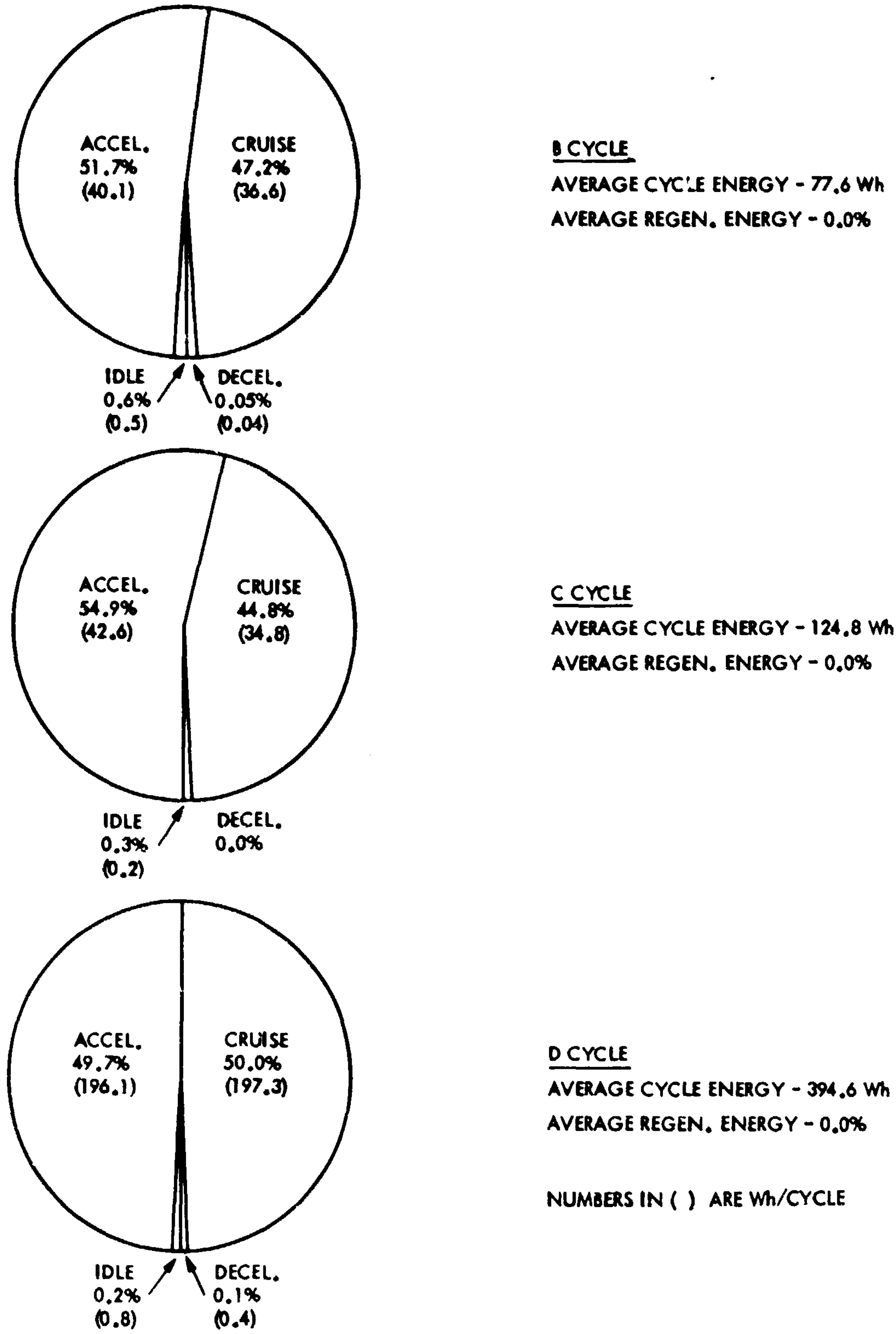


Figure 4-3. Energy Splits for the Jet Industries Electra Van '600'

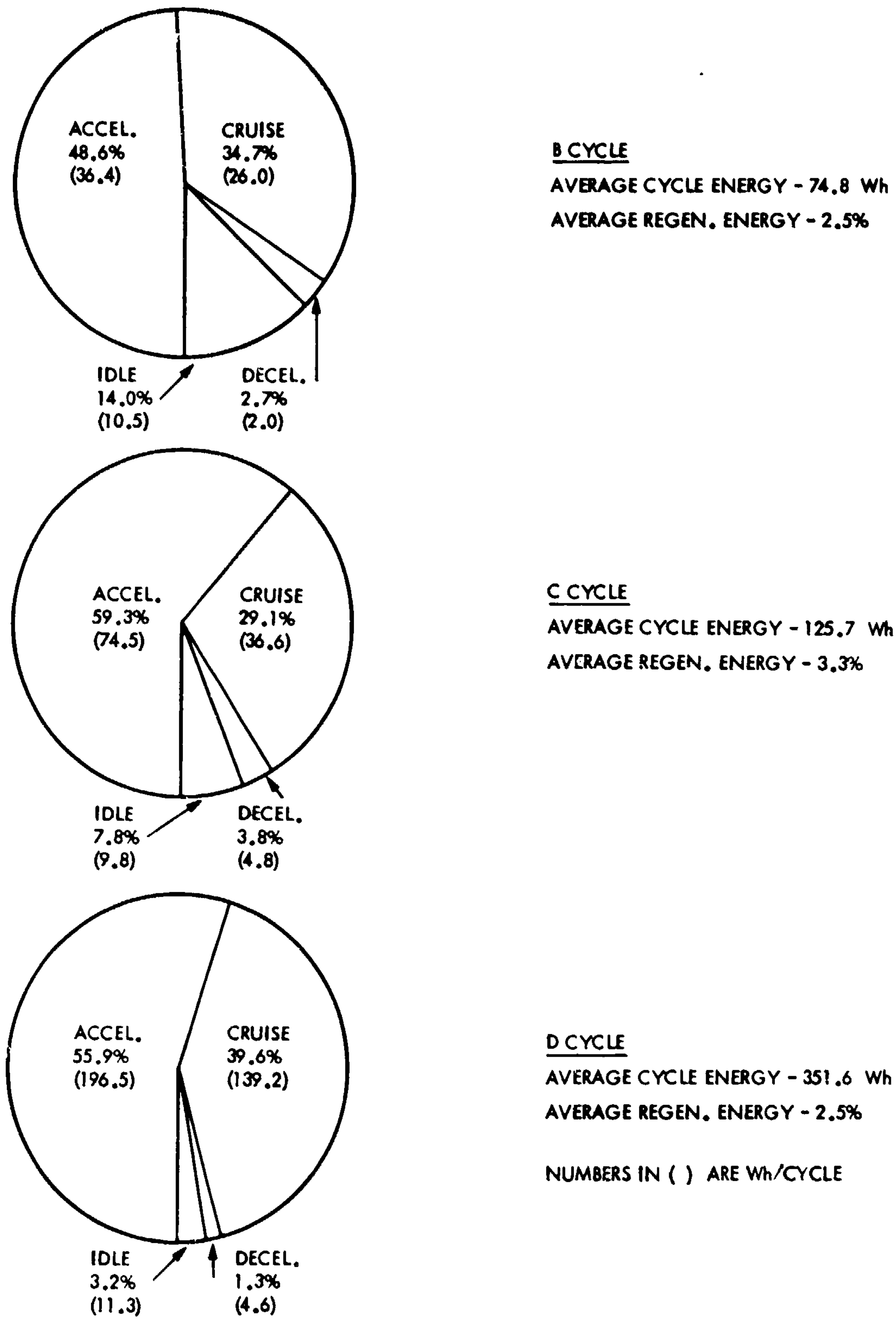


Figure 4-4. Energy Splits for the South Coast Technology R-1 Electric

During deceleration (coast and brake), minimal regenerative energy was returned to the battery. To accomplish regeneration, the controls isolated the series wound field from the armature and connected it directly to the battery through a limiting resistor. Regenerative energy to the battery was then possible when the housekeeping power requirements were satisfied and the armature output voltage exceeded that of the battery. There was insufficient armature voltage to charge the battery below the equivalent of base speed for this "isolated" configuration. Although little regenerative energy was returned to the battery, significant amounts were extracted by "snubbing" the motor. This energy was controlled by the armature chopper and was dissipated as heat in the dumping resistors (additional discussion provided later in this section). Considering the minimal range extending benefits available through regeneration, it is doubtful if the added costs and reduced reliability (because of additional component count) is warranted for this particular technique.

The relatively small percentage of energy consumed during deceleration and idle is the result of several factors. The lack of a motor idle condition, permitted by the series motor/armature chopper combination, is the most obvious. Controller housekeeping energy is relatively small compared to the large percentage of energy needed during acceleration and cruise. The use of an alternator to charge the accessory battery precludes propulsion battery energy consumption during idle.

b. <u>EVA Change of Pace Energy Splits</u>. As was the case for the Battronics truck, the energy splits of Figure 4-2 are dominated by acceleration and cruise losses. Although the AMC Pacer is considered an economy car, its relatively heavy weight makes it a poor selection for EV conversions. This problem was compounded through the use of large heavy steel plates in making the EV changeover (i.e., motor mounting plate, etc.). Although the EVA vehicle has separate motor controls (armature or field), all of the cyclic test data presented here was during armature control (see controller discussion). The relatively poor motor/controller efficiency contributed to the high percentage of energy required during acceleration and cruise.

A significant portion (over 5%) of the EVA's energy consumption occurred during deceleration and idle even though this car was capable of regeneration. A dc-dc converter used to charge the accessory battery and three series connected fans accounted for most of this energy consumption. Because two of the three fans were used to purge both battery compartments, almost 400 W of the 900-W accessory load could be saved by separating the motor fan from those used to purge batteries. A scheme that uses natural air flow during vehicle movement would likely provide adequate safety in the battery compartment during discharge. During deceleration, a relatively sophisticated technique was used to automatically downshift the transmission whenever motor speed fell below base speed, thereby keeping the motor in a regime where regeneration is optimized. The poor reverse coupling of the automatic transmission, however, prevented recovery of meaningful kinetic energy. The sophistication of the controller was of little avail. Recovery of kinetic energy was not sufficient to overcome the demands of the accessories or the controller's housekeeping needs. No regenerative energy was returned to the propulsion battery.

c. Jet 600 Energy Splits. The lighter weight of the Jet van is reflected in the smaller percentage of energy consumed during acceleration (Figure 4-3). Except for the Schedule "B" test, the Jet van exhibited 3 or more percentage points less energy during acceleration than the other vehicles described here. This difference cannot be totally attributed to weight. For example, the SCT-R1 Electric consumed some energy during idle, thereby reducing the percentage of energy consumed during acceleration. The Jet vehicle was not equipped with a dc-dc converter to charge the accessory battery, nor were the motor cooling fans powered by the propulsion battery (JPL had to add additional cooling capacity to keep the motor temperature below 350 degrees F.) The propulsion battery energy requirements were not penalized by the accessory demands as were the two previously discussed vehicles.

Because the motor and controller are not powered during deceleration except for minimal controller housekeeping needs, the energy consumption during deceleration and idle was nil. There was no regenerative charging capability.

d. SCT-R1 Electric. Several factors contributed to the relatively low percentage of acceleration energy indicated in Figure 4-4. Besides sharing the lowest test weight value with the Jet van, the SCT-R1 Electric was the only vehicle using a motor control strategy which relied solely on field weakening. The effects of this strategy on the acceleration and cruise energy splits were twofold: (1) near equal motor/controller efficiencies were evidenced in both the acceleration and cruise modes (see controller discussion) and (2) the energy consumed during idle and deceleration decreases the percentage of total energy used for acceleration and cruise. The need to idle a motor which is only field weakened becomes equivalent to an excessive housekeeping load during non-motive operating conditions. As with the Jet van, the energy requirements for the accessory battery and the cooling fan for the motor are not reflected in the energy splits of Figure 4-4. Motor cooling energy was obtained directly from the accessory battery. Because the dc-dc converter (needed to maintain the accessory battery's charge) did not function, this energy was not accounted for.

The highest regeneration recorded from the four vehicles was by the SCT-R1 Electric. Even here the energy returned to the battery during deceleration was almost negligible, amounting to only 3.3% on the Schedule "C" test. This figure represents only about 4.2 Wh per cycle. Two factors contributed to the SCT's low regenerative energy:

(1) Downshifting was not permitted during deceleration. Had downshifting been allowed, higher regeneration would have been realized, as the motor would have been kept above base speed longer. Downshifting was not allowed in the manufacturer's recommended driving procedure, nor did JPL feel that downshifting would be done by the average EV operator.

(2) Regeneration was only available when the motor was above base speed. Because the cruise portion of any driving schedule was always done in the highest possible gear, as defined by the manufacturer's recommended

shift points, only small quantities of regeneration could take place until the motor was disengaged to preclude the motor from being forced below base speed. From a controller viewpoint, the regeneration is obtained at no cost.

The SCT-R1 Electric also exhibited the highest energy consumption of the four vehicles during idle. During the Schedule "B" test, this idle loss accounted for a full 14% of the discharge energy per cycle. Idle energy consumption, as a percentage of a total cycle, always exceeded the percentage of regenerative energy by at least a factor of two. The 1500 W needed to idle the motor during "brake" and "idle" becomes a significant penalty during any driving pattern having frequent or extended stops. Additional information on the attributes and drawbacks of the controls used by the SCT-R1 Electric can be found in the Test Report of the Cutler-Hammer Corvette (Ref. 10).

2. Battery Power and Energy Comparisons

Figure 4-5 shows the average battery power[1] required for each vehicle at constant speed and Figure 4-6 shows the average battery power required for the acceleration, cruise, and idle portions of the J227a driving schedules. These figures show that the SCT vehicle required considerably less power under nearly all conditions. Several factors contributed to the SCT's superior energy economy:

(1) Lowest weight, equal to the Jet vans, which was a significant benefit during the acceleration modes of cyclic tests.

(2) Most efficient controller; only the field was subjected to chopping losses.

(3) Lowest road-load requirements.

In making these comparisons, it must be remembered that Battronic truck was not intended for use as a passenger vehicle, but rather as a utility truck

[1]Average power was obtained by dividing the total battery discharge energy by test duration (elapsed time) and then averaging this value with those from repeat tests.

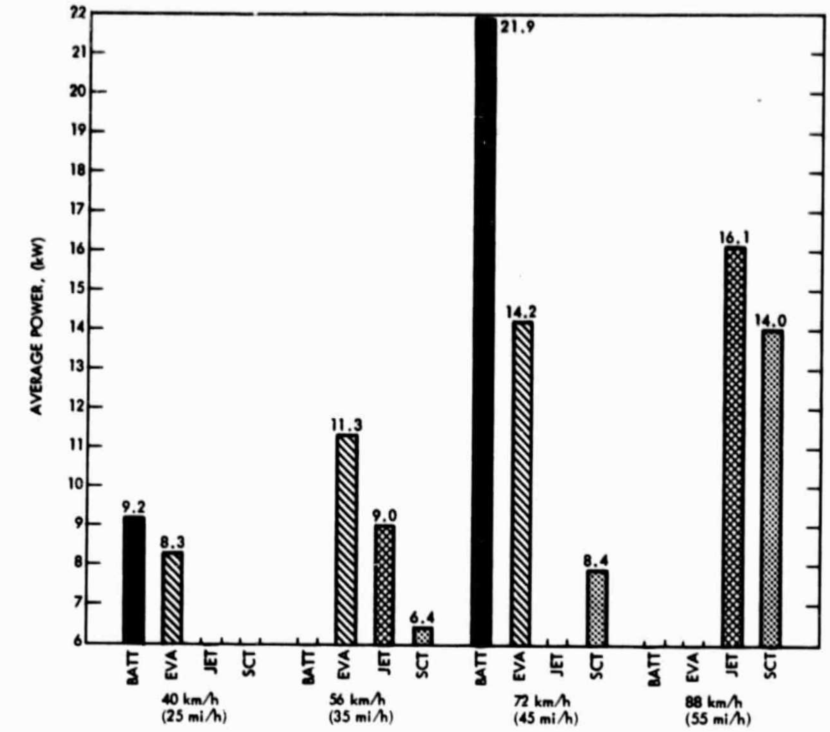


Figure 4-5. Constant Speed Battery Power

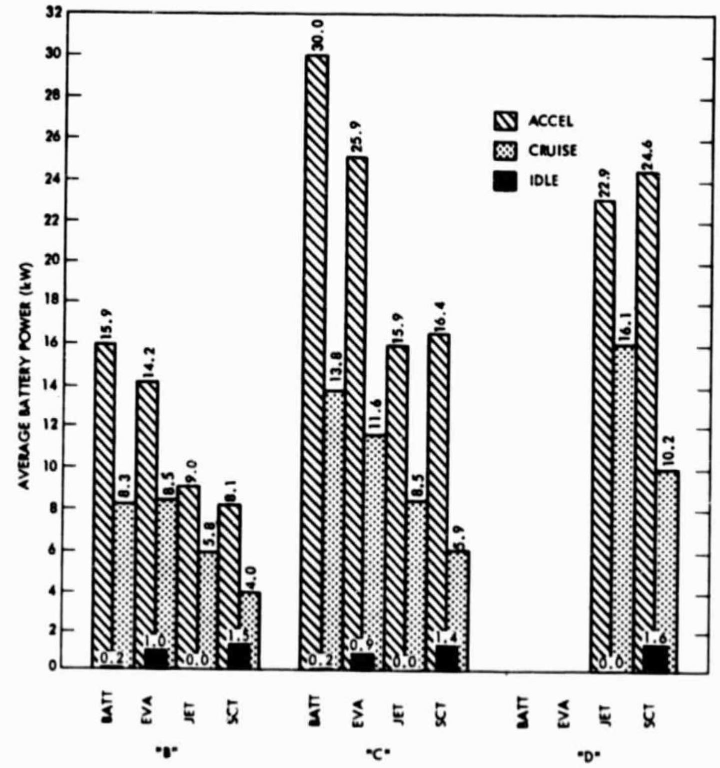


Figure 4-6. Battery Power vs Driving Mode for SAE J227a Cycles

which would be expected to demonstrate higher energy requirements per mile traveled. The truck's high weight and frontal surface areas were primarily responsible for its poor performance compared to the other upgrade vehicles.

The energy required from the battery per unit of distance traveled (energy consumption) as a function of vehicle speed is shown graphically in Figure 4-7. As expected, energy consumption increased with speed because of the higher rolling resistance and aerodynamic drag (with the exception of the EVA Change-of-Pace). The increase in energy economy with increased speed exhibited by the EVA vehicle explains the abnormal speed vs. range characteristic presented in Section V. As shown in the following discussion on controllers, the efficiency of the EVA's controller increased by approximately 8% between 40 and 72 km/h. The combined motor/transmission efficiency was about 25% higher at 72 km/h than at 40 km/h. These effects combined to increase the overall drivetrain efficiency (battery to road) sufficiently to overcome the increased road load at the higher speed.

B. COMPONENT CHARACTERISTICS

1. Controller Introduction

Three different types of motor/controller systems were implemented in the four vehicles tested. The Battronic and Jet vehicles employed series wound motors with armature choppers. The EVA vehicle used a separately excited motor, and was the only vehicle of the group using both armature and field choppers. Both the Battronic and Jet vehicles used Silicon Controlled Rectifiers (SCRs) exclusively in their motor/controllers. EVA's controller used SCRs in the armature chopper and transistors in the field chopper. The SCT vehicle used a separately excited motor and a transistorized field chopper, with the armature being connected directly to the battery. To avoid excessive start-up currents, a relay and starting resistor were used to bring the SCT's motor up to base speed when the vehicle was "started."

The following discussion examines the efficiencies of the four controllers during various modes of operation. Many factors affect controller efficiency,

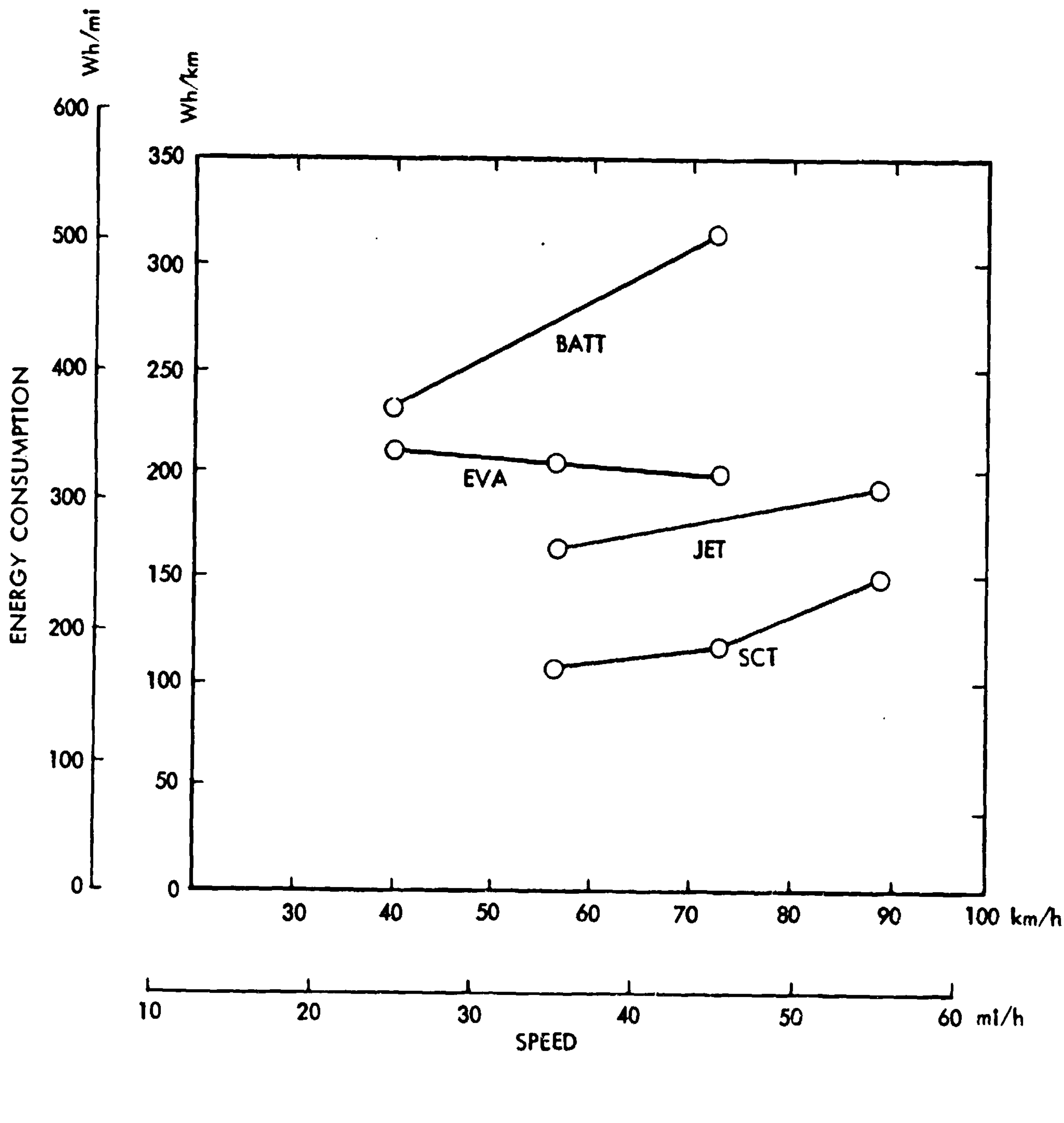


Figure 4-7. Average Energy Consumption vs Speed

including design, the choice of components, system voltage, and power levels. Matching the controller to the motor is also an important consideration, particularly under conditions of pulsed operation.

2. Average Controller Efficiency

The overall energy efficiencies for each type of test performed are presented for each of the four controllers in Table 4-1. The efficiencies were derived by dividing the sum of the measured energy inputs to the motor (i.e., armature energy plus field energy if applicable) by the measured quantity of energy extracted from the battery. The energy values used herein are the averages obtained by combining all valid tests of the same type. These data then include the effects of vehicle warm-up on power requirements and the effects of declining battery voltage as the test progresses to battery depletion. Before discussing the controllers for each individual vehicle, it is appropriate to denote the loss mechanisms associated with each type of controller.

The SCRs are solid-state devices capable of switching the large currents and withstanding the voltages needed for EVs. Once the SCR switch is turned on, it can only be turned off by interrupting the current flowing through it. In other words, SCRs are not capable of turning themselves off as long as current is flowing through them. To achieve motor/control through the use of SCRs, "commutation" circuitry is added to the controller. In the case of the vehicles discussed here, energy is stored in capacitors until the controller commands the main SCR to be turned off. At this point, the charged capacitors are discharged into the motor downstream of the main SCR. Sufficient energy is released from the storage capacitors that the motor is powered solely by the stored charge and the main SCR becomes reverse biased. At this point, the main SCR turns off and waits for the controller to turn it back on. This switching process is repeated approximately 500 times per second and provides an essentially continuous control of the motor by varying the on-off time of the SCR.

The relatively slow switching speed of the SCR coupled with housekeeping power requirements during commutation result in a relatively constant amount

Table 4-1. Average Controller Efficiency (%) Vs. Test Type

	J227a "B"	J227a "C"	J227a "D"	40 km/h (25 mi/h)	56 km/h (35 mi/h)	72 km/h (45 mi/h)	88 km/h (55 mi/h)
SCT	99.2	99.3	99.4	—	98.7	98.9	98.6
JET	91.7	93.3	94.6	—	92.3	—	96.4
BATT	—	—	—	81.3	—	92.7	—
EVA	—	—	—	89.8	91.6	96.7	—

of power being dissipated internal to the controller but independent of the throughput (motor) power. As such, the higher the throughput the smaller the controller percentage losses. This problem of poor controller efficiency at low throughput (vehicle power demands) is compounded by poorer motor efficiencies during high crest factor pulsed operation. As power requirements increase, crest factor decreases, thus resulting in enhanced motor and controller efficiencies. These poorer controller efficiencies are reflected in the data presented in Table 4-1 which shows that the vehicles having SCR controllers exhibited poorer efficiencies.

a. Battronic Controller. A somewhat unique scheme was used by Battronic to achieve regeneration capability from a series wound motor. Engagement of the brake pedal would cause the motor's armature to be isolated from the series field. The field was connected directly between the propulsion battery and the SCR chopper normally used to control the series combination of the field and armature. The isolated armature (with its polarity reversed) was connected directly across the propulsion battery through steering diodes. Field excitation was then provided by the armature chopper and regeneration was available to the battery. However, shunt fields require considerable excitation current to make the armature a useful generator. Combining the high excitation currents with the large housekeeping losses for the controller results in an extremely inefficient means of returning inertial energy to the battery. Figure 4-8 demonstrates power levels in and out of the battery and motor during two cycles of a J-227a

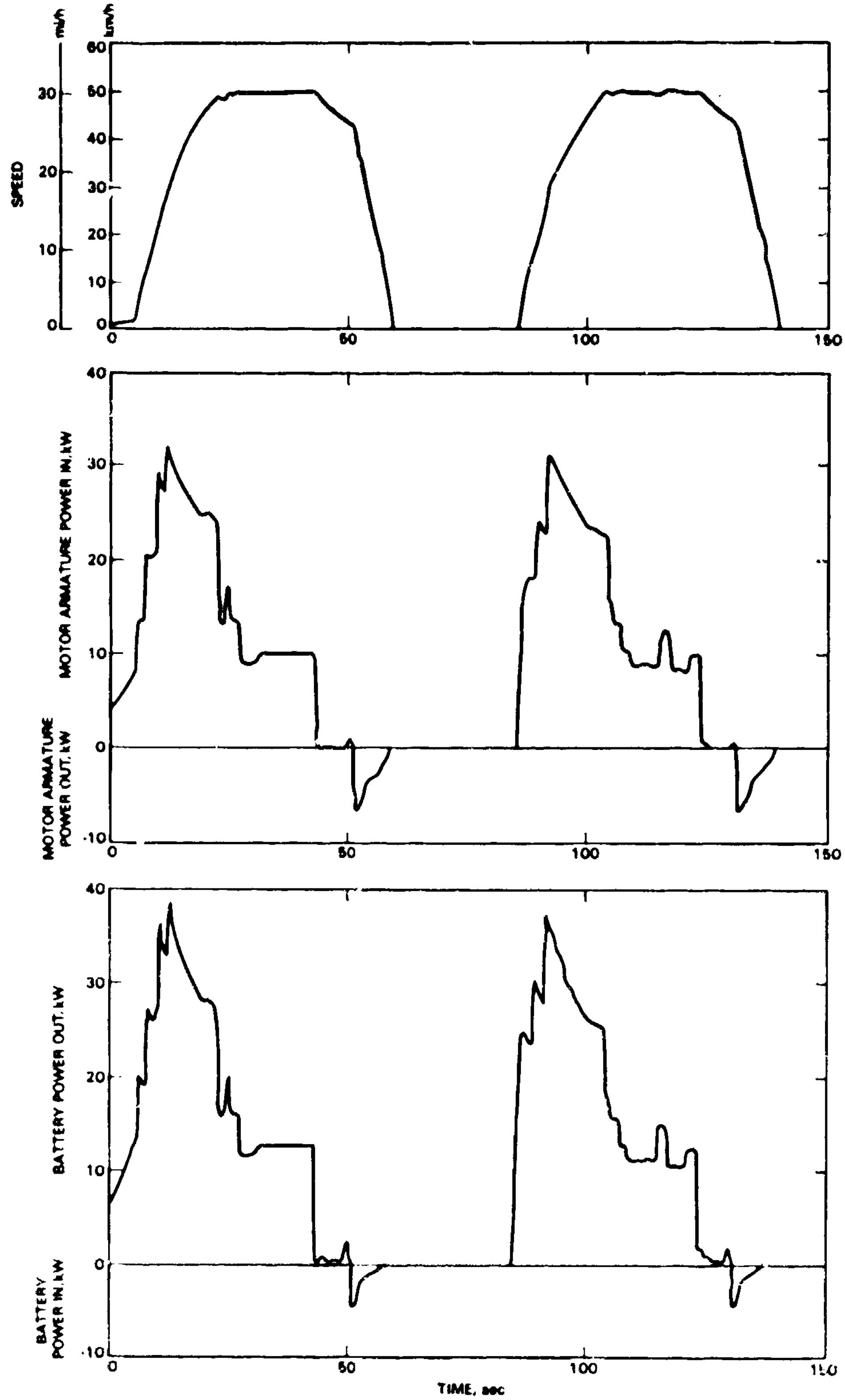


Figure 4-8. Battronic Volta Pickup Vehicle Speed, Battery and Motor Armature Power

Schedule "C" test. It can be seen that the peak regenerative power from the armature is 7 kW, and the peak regenerative power into the battery is only 4 kW. The effects of this inefficiency are reflected in the differences in regenerative energy from the the motor versus what went back into the battery. During test #6, Schedule "C", 0.451 kWh was observed as regenerative energy from the motor, yet only 0.207 kWh was returned to the battery. This 46% regeneration efficiency was a major factor in explaining why the percentage of battery regeneration energy was less than 2% of the total discharge energy. Considering the small quantity of energy returned to the battery, it is questionable if the added complexity of the controller is warranted.

During the constant velocity testing, the Battronic Cableform controller required the highest internal housekeeping power, dissipating an average of 1.5 kW. Much of this power was lost in the excessively large commutation storage capacitors. As can be seen in Figure 4-9, the controller losses for the Battronic vehicle exceed those of the other controllers reported here both on an absolute and a relative basis. Oscillograms of the controller voltage and current waveshapes are provided in Figures 4-10 and 4-11.

Although not quantified during testing at JPL, the relatively high controller losses were coupled with similar efficiency degradation for the motor. Even though the magnitude of degradation will vary considerably from motor to motor, it is generally acknowledged that dc motors suffer a decline in efficiency during pulsed operation and that these losses are a function of the crest factor of pulsed current among other things. The high controller losses exhibited by the Battronic controller, therefore, were compounded by less efficient motor operation (additional discussion on motor losses during pulsed operation is provided later in this section).

b. EVA Change-of-Pace Controller. EVA also employed a Cableform controller to drive their motor. This controller had an SCR armature chopper and a transistor field chopper. The separately excited dc motor was

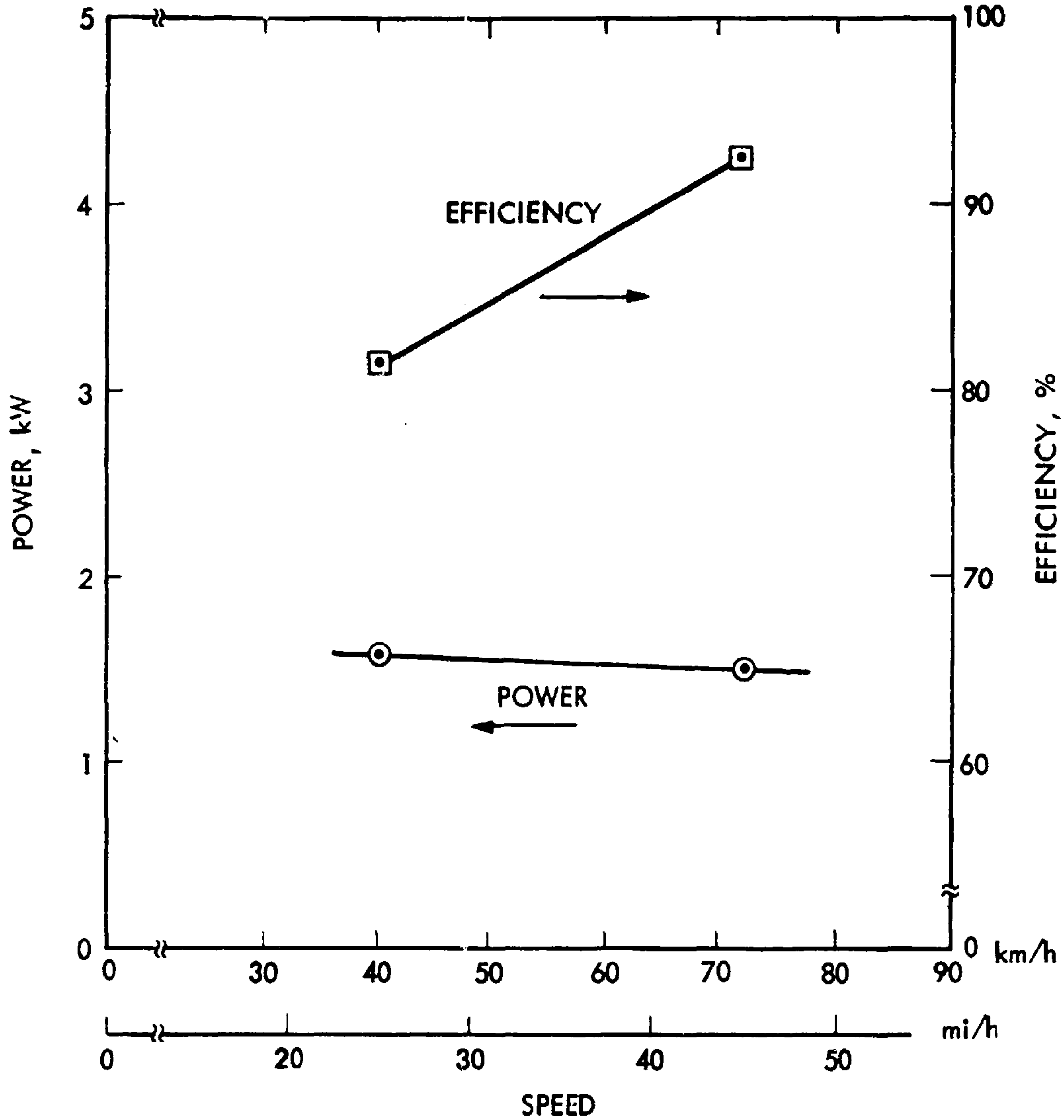


Figure 4-9. Battronic Controller Power Losses and Efficiency During Constant Speed Tests

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Battery

40V/div
100A/div

V

A
0V & 0A

0.5 ms/div

Figure 4-10. Battronic Volta Pickup Battery Waveshapes 40 km/h (25 mi/h)

Battery

40V/div
100A/div

V

A

0V & 0A

0.5 ms/div

Figure 4-11. Battronic Volta Pickup Battery Waveshapes 72 km/h (45 mi/h) controlled by armature chopping below base speed and field weakening above base speed. As with the Battronic controller, the EVA was also capable of regeneration. Above base speed, sufficient voltage was developed (during regeneration) to return energy to the propulsion battery, but below base speed there was insufficient voltage. To provide regenerative braking below base speed, the armature chopper was used as a controlled short across the armature to "snub" (brake) the motor. The apparent motor/transmission control algorithm was to upshift the transmission during acceleration as soon as the motor achieved base speed. During deceleration, downshifts would occur when the motor fell below base speed. In other words, transmission shifts were commanded by the controller each time a transition was made from armature chopping to field weakening or vice versa.[2] This control strategy should enhance regenerative battery charging by keeping the motor above base speed as long as possible (via transmission downshifts) during deceleration. All of this relatively elaborate control, however, was of little avail as the regenerative energy returned to the battery was nil. The reverse coupling of the Pacer's torque converter was poor (by design), thereby precluding the possibility of transmitting the stored inertial energy back to the battery. Figure 4-12 presents data from two cycles of a Schedule "C" test which demonstrate that once regeneration is initiated the motor quickly approaches zero speed because of the lack of coupling in the transmission's backwards torque path.

Controller efficiency and loss data for the Change-of-Pace is provided in Figure 4-13. As with the previous Cableform controller (Battronic), considerable power is required for housekeeping and SCR commutation during the armature chopping mode of operation. Some insight into the differences in controller efficiency is demonstrated, fortuitously, by having two different modes of operation at 72 km/h (45 mi/h). Voltage during tests with the Yardney Ni-Zn battery was sufficiently high to raise the motor's base speed just above 72 km/h (45 mi/h) compared to the base speed corresponding to about 61 km/h (38 mi/h) for the baseline battery. During the baseline 72 km/h (45

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[2]This postulated control strategy is based on observations of the vehicle's operation and an analysis of the recorded data. It has not been verified with the vehicle manufacturer.

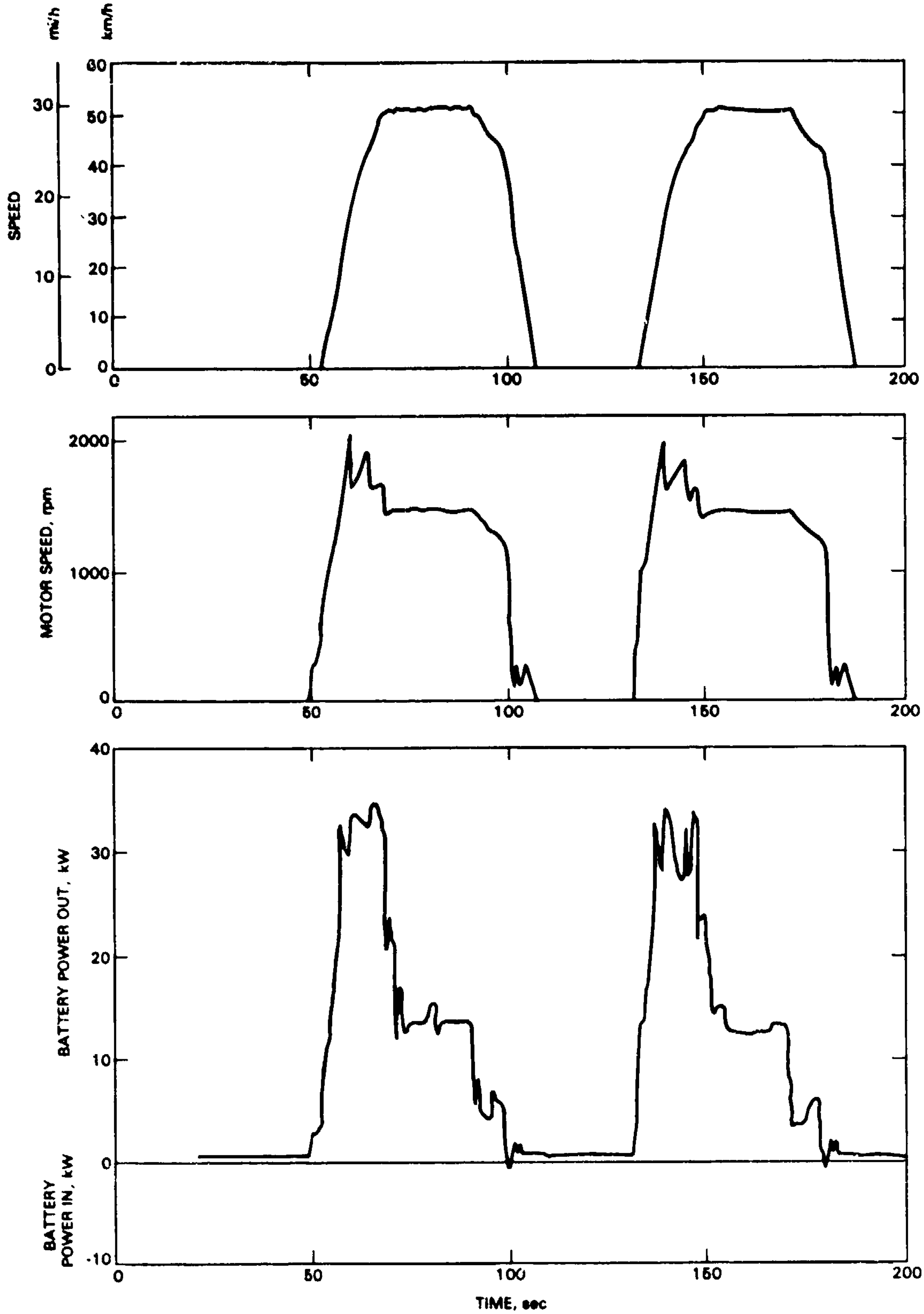

Figure 4-12. EVA Change-of-Pace Vehicle Speed, Motor Speed, and Battery Power

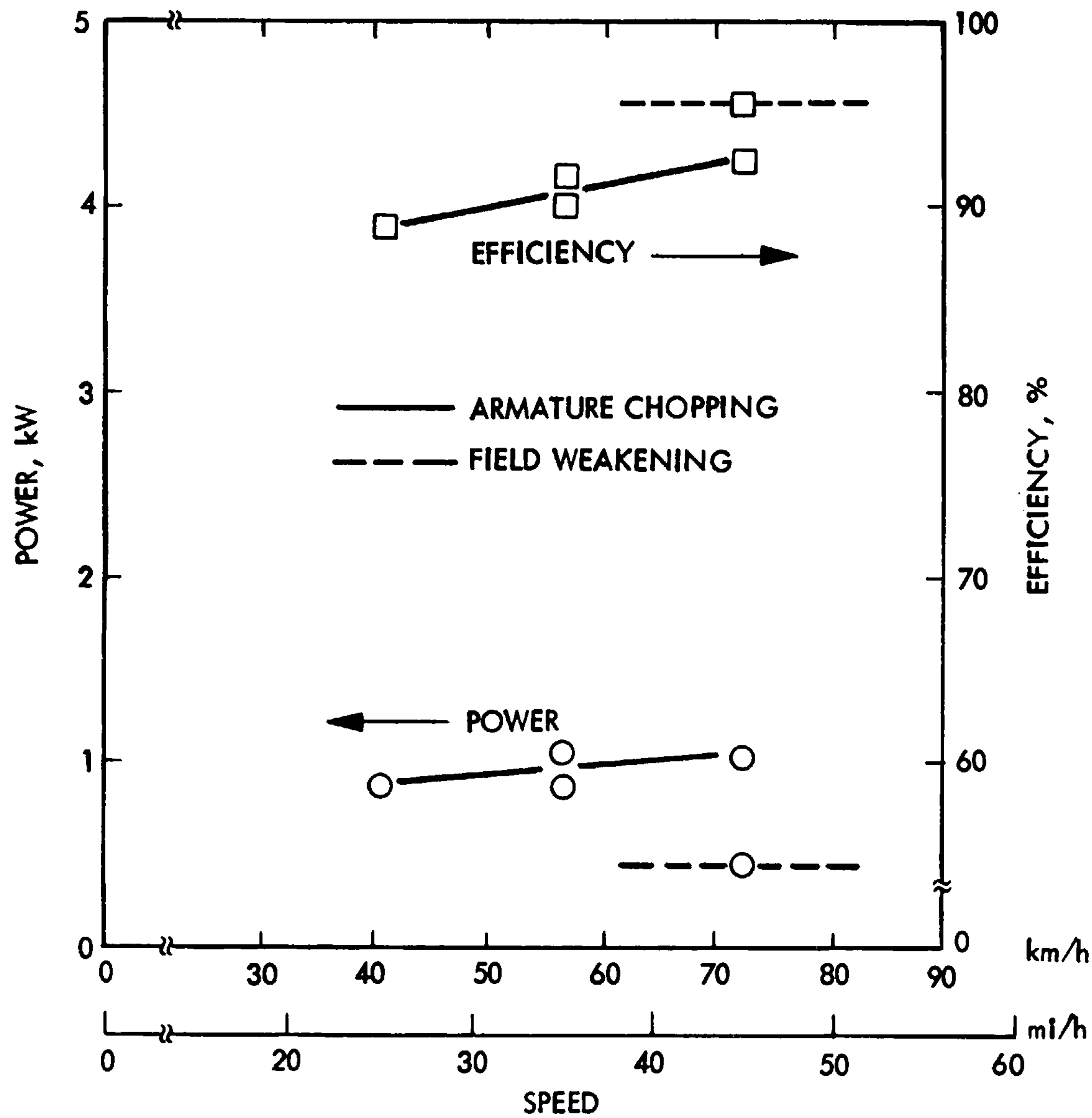

Figure 4-13. EVA Change-of-Pace Controller Power Losses and Efficiency vs. Speed

mi/h) tests the controller losses were under 0.6 kW compared to the losses of over 1.3 kW during the Yardney (armature chopping) tests at the same speed.

Oscillograms of the controller, voltage, and current waveshapes are presented in Figures 4-14, 4-15, and 4-16 for the baseline battery constant velocity tests. Figure 4-17 was obtained from the Yardney 72 km/h (45 mi/h) test just discussed. It can be seen that armature chopping is occurring here, but not during the same speed test for the baseline battery shown in Figure 4-15. As with the Battronic controller, motor efficiency will also suffer during the armature chopping mode of operation.

c. Jet Controller. Only the Jet van was without regenerative braking capability. Jet Industries had initially intended to supply this capability; however, this was predicated upon General Electric following through with their intended development of a controller to replace the EV-1. General Electric's decision to discontinue development of the SCR-type controller occurred late in the Jet van construction and therefore prevented installation of any controller but the original Jet controller, the EV-1.

As shown in Figure 4-18, the EV-1 controller in the Jet mini van was the most efficient of the three SCR controllers in this report. Part of this higher efficiency resulted from the use of marginal cooling fans for the controller. To keep the controller from current limiting because of excessive internal temperatures, JPL added cooling capacity beyond that supplied with the vehicle. The energy needed to drive this added blower is not accounted for in Figure 4-18. Waveshapes of the battery and motor parameters are provided in Figures 4-19 and 4-20.

Once the controller heating problem was solved, test durations became sufficiently long that motor overheating became a problem. An additional (larger) blower was added to cool the motor; however, the Jet van's motor continued to run considerably hotter than those of the other 2 x 4 Vehicles (see discussion later in this section).

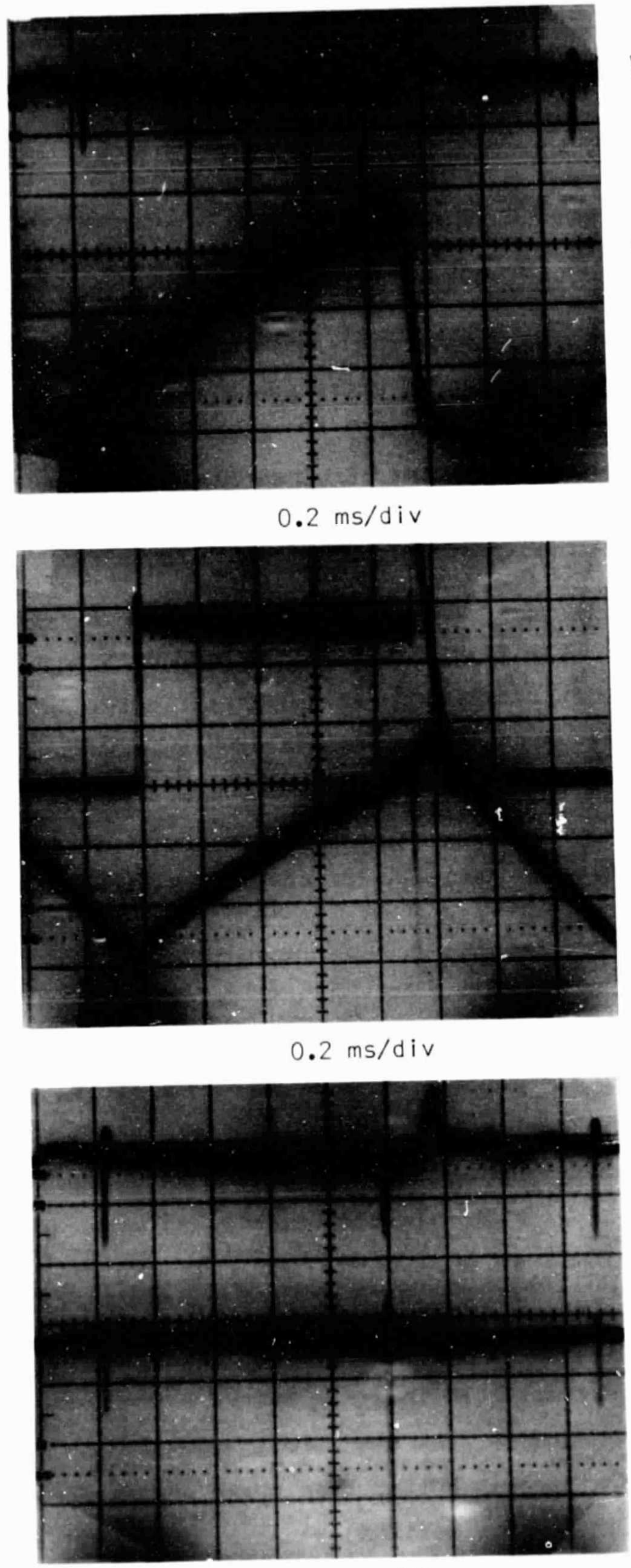

Figure 4-14. EVA, Change-of-Pace Battery and Motor Waveshapes
40 km/h (25 mi/h)

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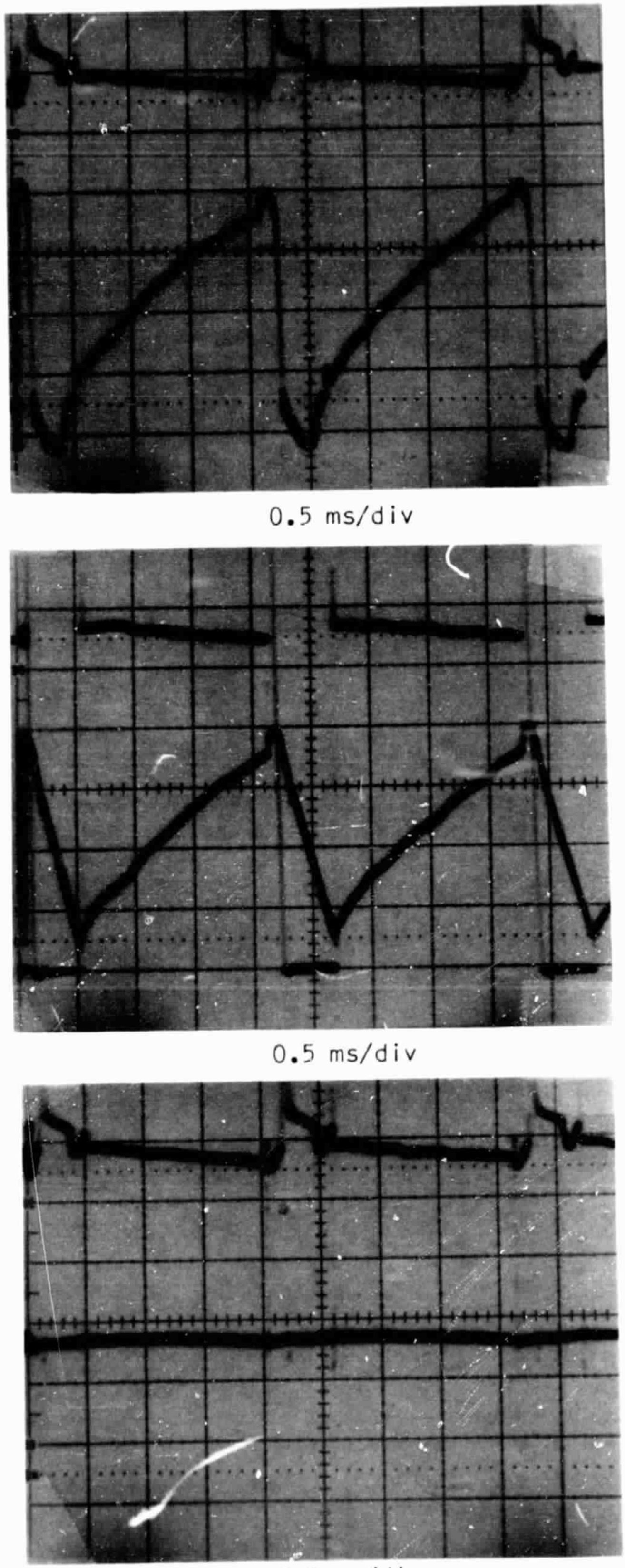

Figure 4-15. EVA, Change-of-Pace Battery and Motor Waveshapes
56 km/h (35 mi/h)

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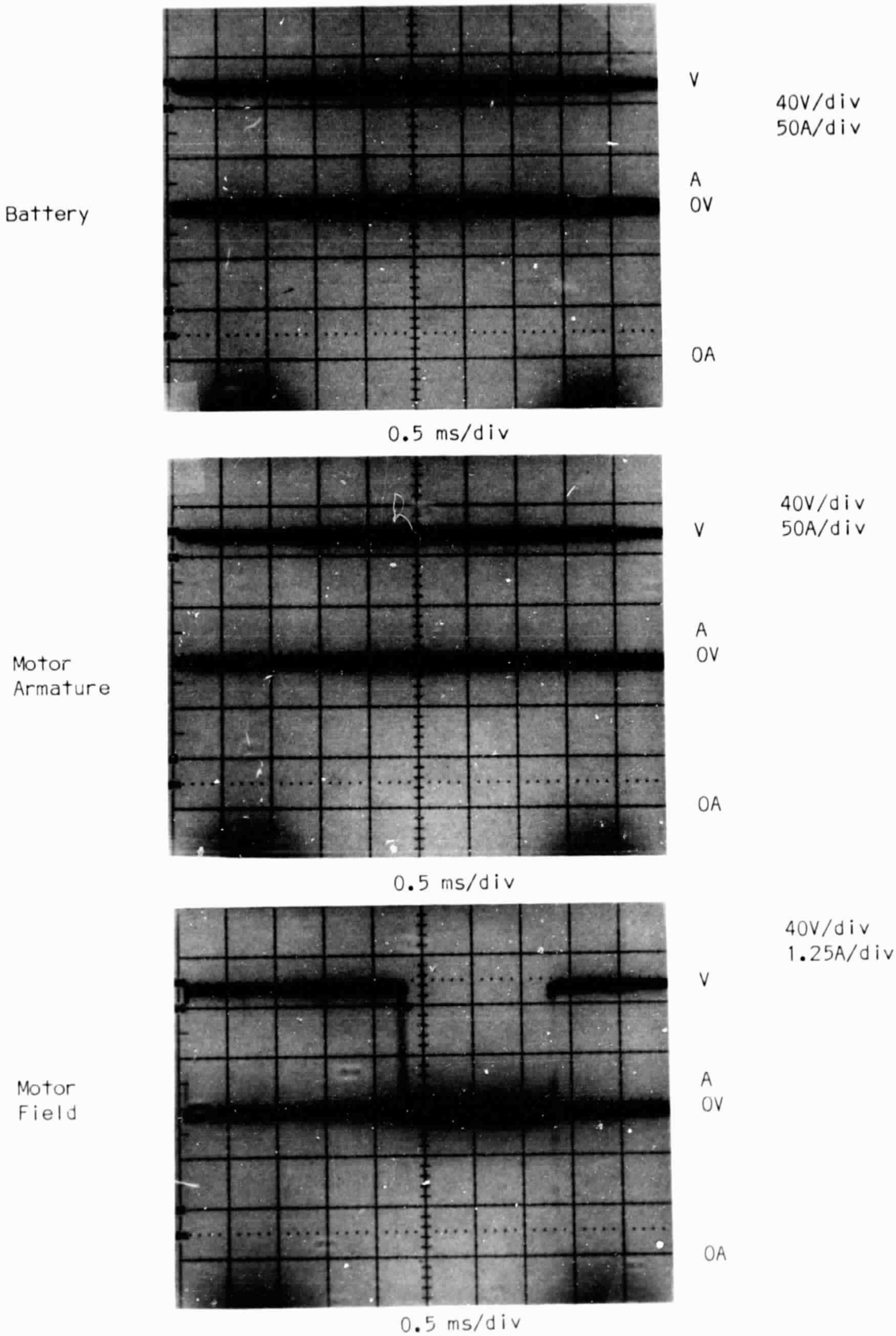

Figure 4-16. EVA, Change-of-Pace Battery and Motor Waveshapes
72 km/h (45 mi/h)

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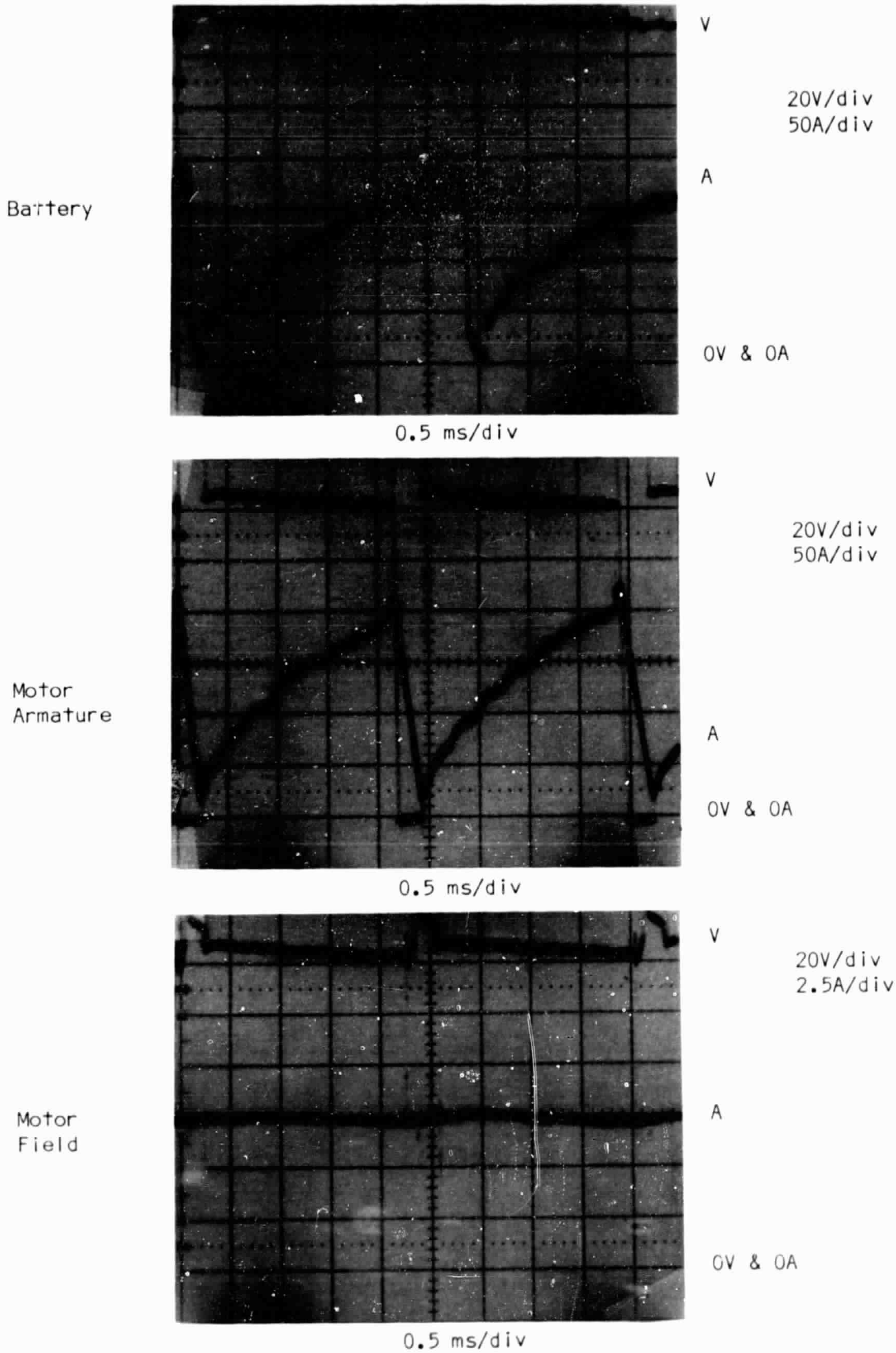

Figure 4-17. EVA, Change-of-Pace Battery and Motor Waveshapes
72 km/h (45 mi/h)

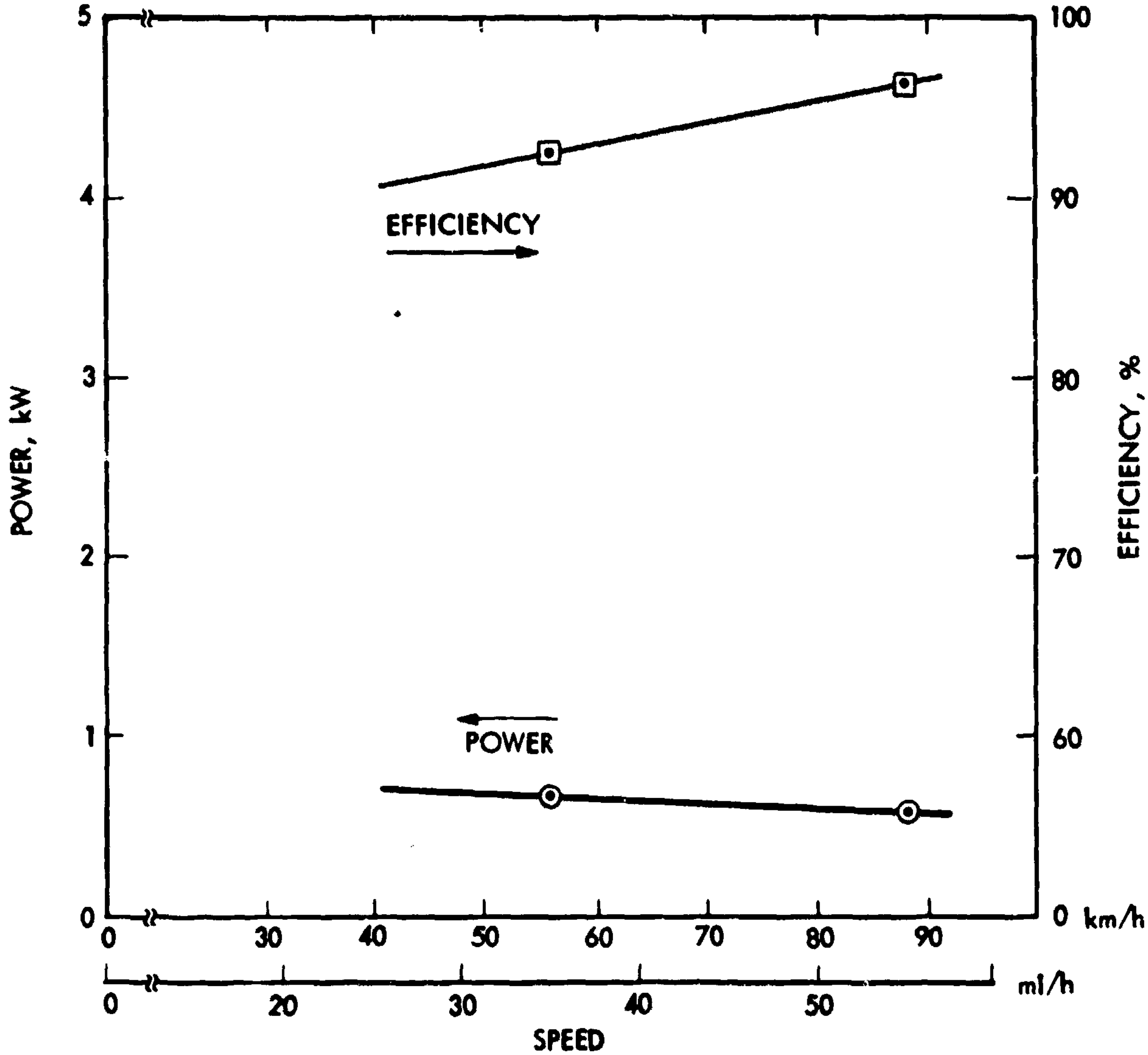

Figure 4-18. Jet Controller Power Losses and Efficiency vs. Speed

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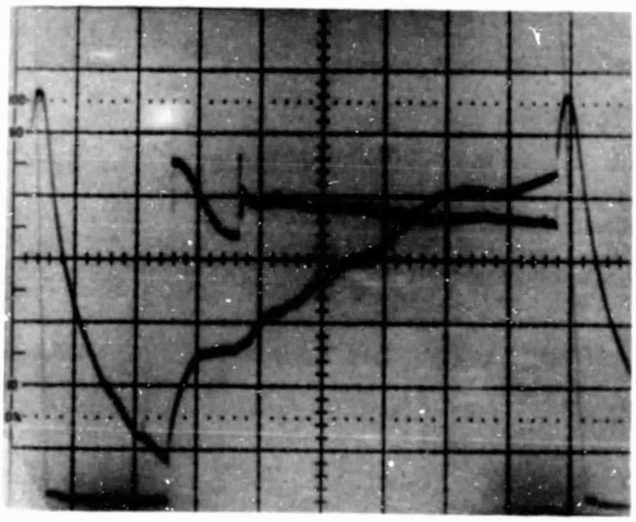
20V/div
50A/div

Motor



A

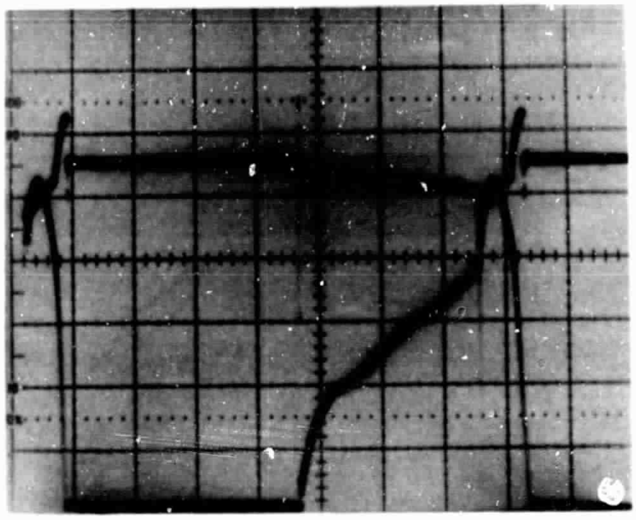
V
OV & OA

0.5 ms/div

Figure 4-19. Jet Industries - Mini Van Motor Waveshapes
72 km/h (45 mi/h)

20V/div
50A/div

Battery



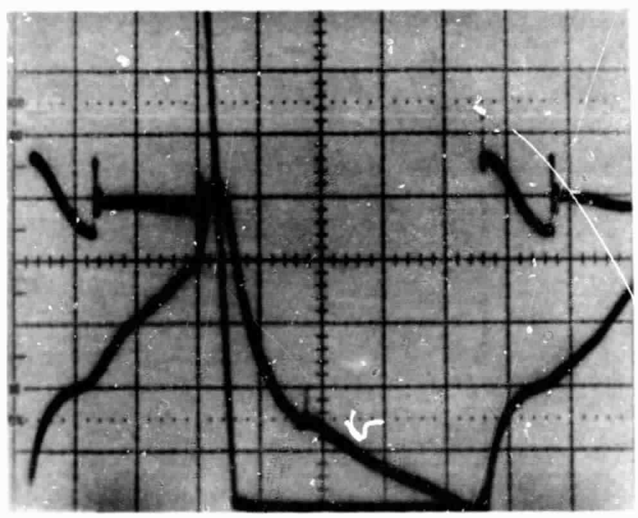
V

A
OV & OA

0.5 ms/div

20V/div
50A/div

Motor



V

A

OV & OA

0.5 ms/div

Figure 4-20. Jet Industries - Mini Van Motor Waveshapes
40 km/h (25 mi/h)

d. SCT R-1 Electric Controller. South Coast Technology employed the simplest motor control strategy of the four vehicles. The separately excited motor was controlled by field weakening. Any time the motor was forced above its base (idle) speed, it was automatically capable of regenerative braking. Although no additional controls are required to achieve regeneration, this control technique was not without penalty. The motor must idle at a relatively high speed (approximately 1800 rpm for the R-1 Electric) which requires some energy consumption during non-propulsive periods (i.e., idle, coast or brake). The penalty associated with this idle (base speed) condition is defined earlier in this section. Although the controller's efficiency is relatively good in the regenerative mode, the energy returned to the battery was not appreciable. During the J-227a Schedule tests, the "cruise" segment was driven with the motor slightly above base speed. Because downshifting was not done during decelerations, there was very little opportunity for regeneration before the motor needed to be declutched from the drivetrain. Without disengagement of the motor, the drivetrain would have been forced below base speed thereby initiating motor shut-down.

Because only a small part of the total motor power is manipulated by the field-only controller, its efficiency is excellent when referenced to total battery power as exhibited in Figure 4-21. Despite this high efficiency, the combined motor/controller efficiency could have been easily enhanced by increasing the repetition rate of the field chopper. The large fluctuations in armature current shown in Figures 4-22 and 4-23 are a direct result of the slow (20 Hz) field chopping rate. Although the improvements gained by increasing the repetition rate are small, they are without cost or other efficiency penalty. In fact, the reduced motor heating (i.e., less eddy-current and resistive heating) would only enhance overall performance and reliability.

3. Motor Efficiency Discussion

In-situ measurements of motor torque are difficult (and costly) during complete system level tests. Because motor efficiency, by itself, is

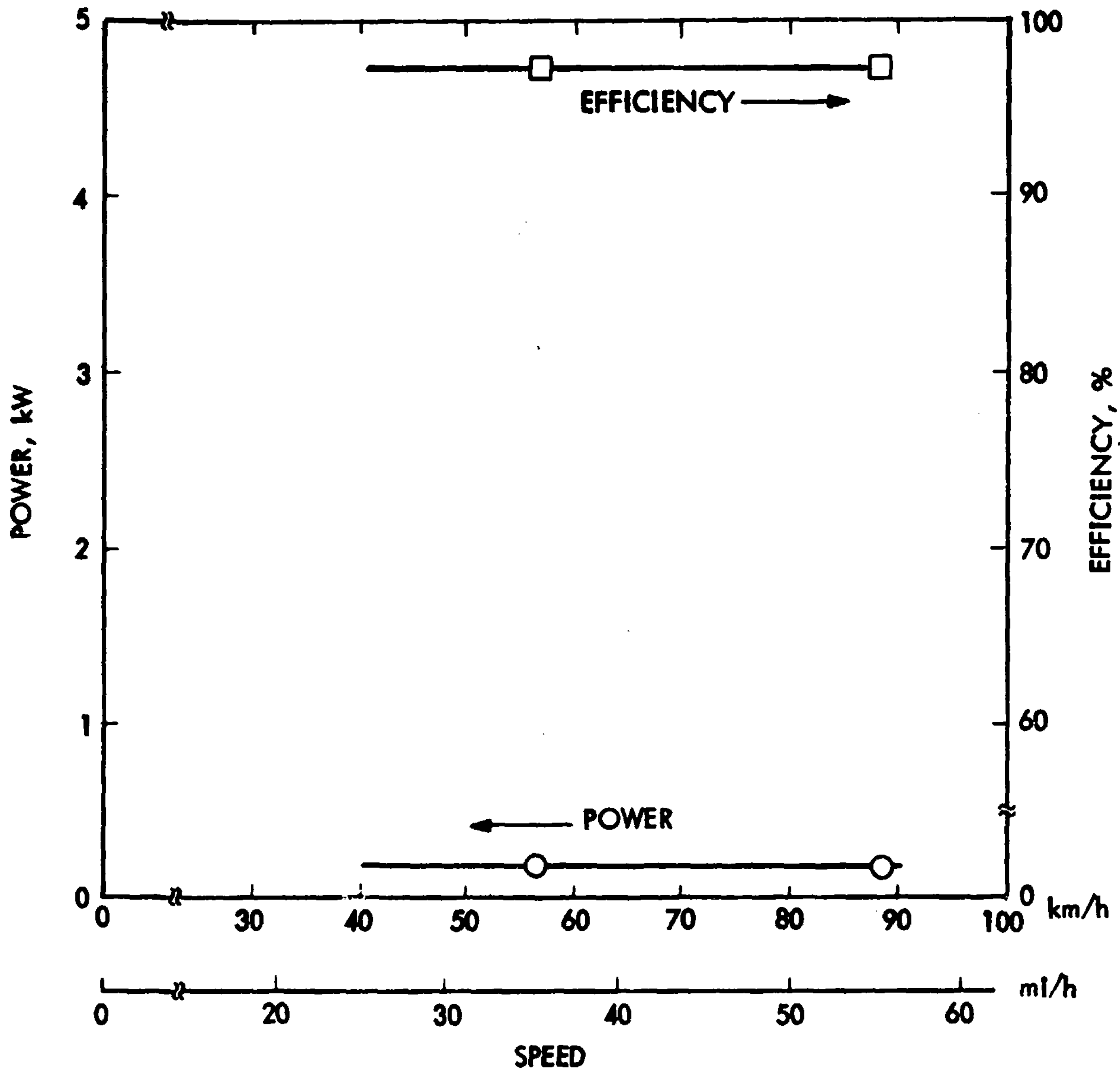
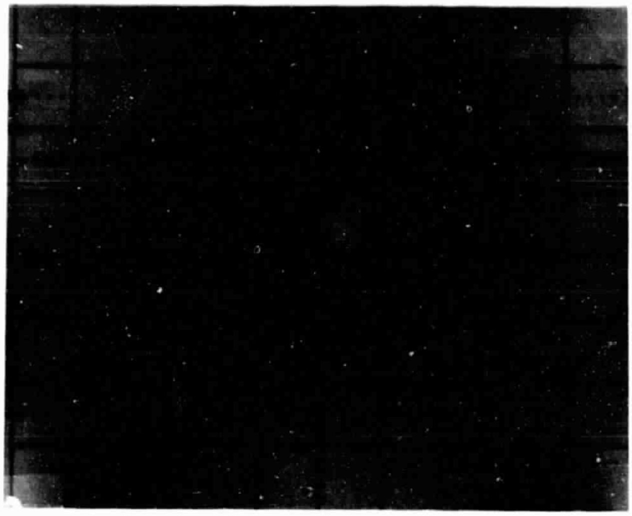


Figure 4-21. SCT R-1 Electric Controller Power Losses and Efficiency vs. Speed

Battery



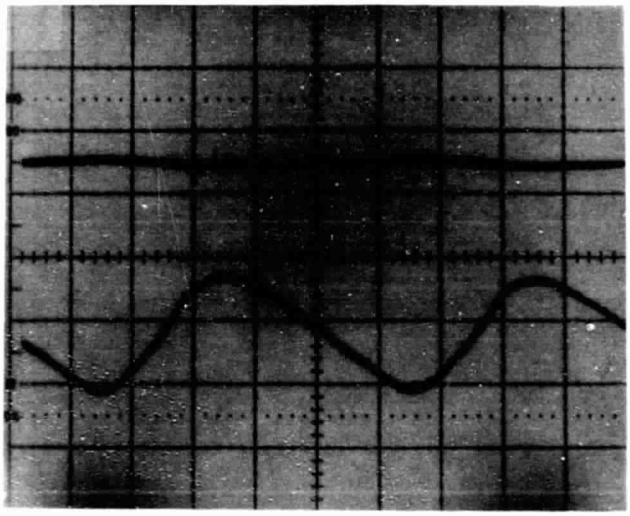
V 20V/div 25A/div

A

0V & 0A

10 ms/div

Motor



20V/div 25A/div

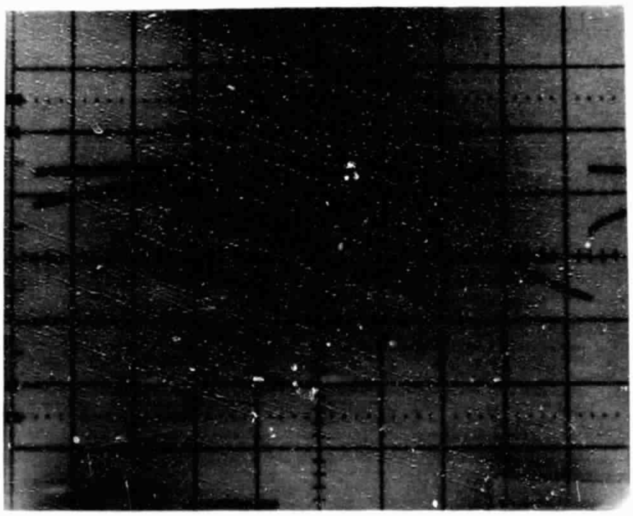
V

A

0V & 0A

10 ms/div

Field



20V/div 1.25A/div

V

A

0V & 0A

10 ms/div

Figure 4-22. SCT, R-1 Electric Battery and Motor Waveshapes
56 km/h (35 mi/h)

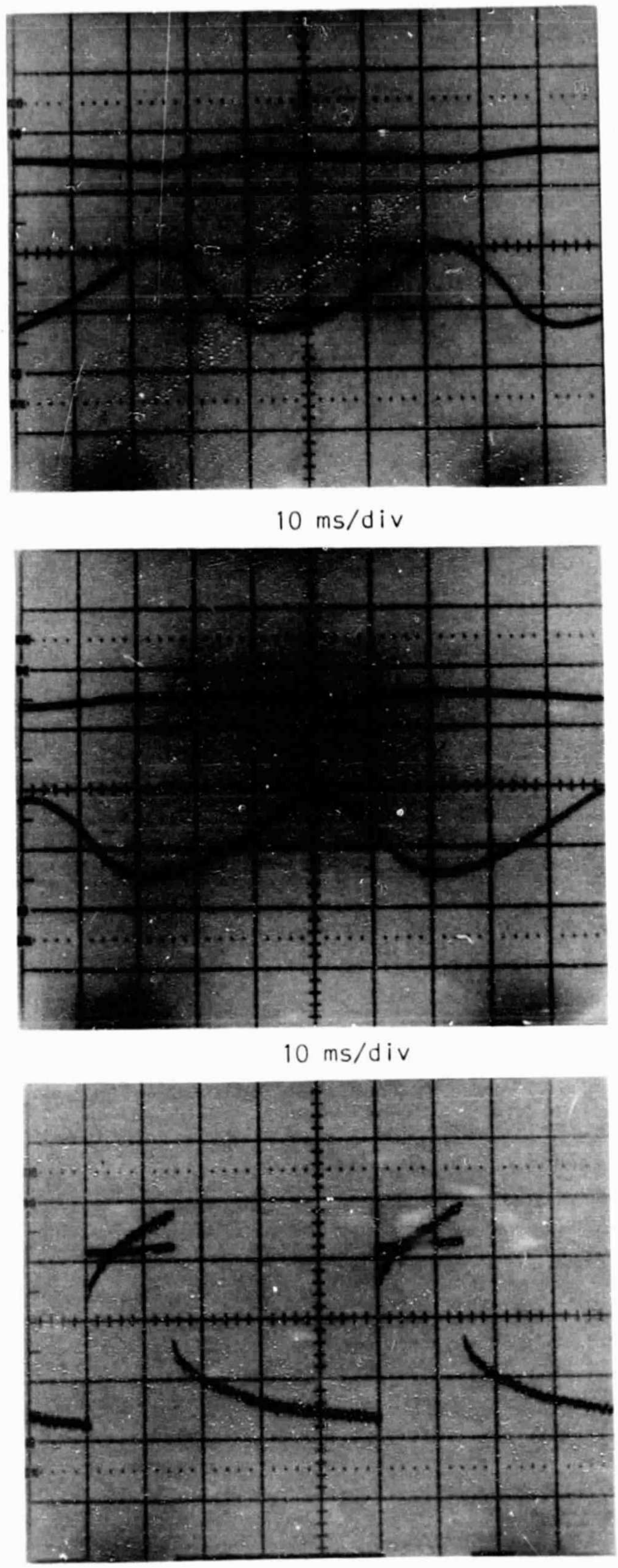


Figure 4-23. SCT, R-1 Electric Battery and Motor Waveshapes
88 km/h (55 mi/h)

of little benefit in analysis of the battery-to-vehicle interactions, this measurement was not justified. On the other hand, the above controller discussion would not be complete without insight into the motor's sensitivity to the characteristic of the device controlling it.

Although there is no efficiency data for the specific motors in combination with the specific controllers found in the 2 x 4 Vehicles, the general decline in efficiency as a result of chopped dc is available in a Lewis Research Center (LeRC) report (Ref 12). Data from a motor similar to the ones in the Battronic and Jet vehicles (series wound) is reproduced in Figure 4-24 (Ref. 12). Like the SCR controllers, motor efficiency is the poorest under conditions of partial power, as displayed in this figure. Most SCR controllers vary the chopping repetition rate as a function of motor power requirements to minimize the combined motor/controller losses but their resulting efficiency leaves room for considerable improvement. This is especially true under low (partial) power conditions typical of level road-load requirements.

The Jet and Battronic vehicles both have series wound motors, but the Jet motor has a solid case compared to the laminated Battronic motor case typified in Figure 4-24. The solid cased motor is a poor selection for use with chopped dc because of the added eddy current losses. Although these losses were not directly quantified, their effects are observed in the motor case temperatures provided in Figures 4-25 and 4-26. As previously indicated, the non-laminated Jet motor got far hotter than any other during JPL testing. Motor current is also graphically presented in these figures and demonstrates that both motors are drawing similar current levels.

Figures 4-25 and 4-26 also reinforce previous statements. Toward the end of each test, motor temperature starts to decline despite the fact that motor current is increasing to compensate for declining battery voltage. As current is increasing, the ripple content of the chopped motor current declines, thereby reducing eddy-current losses. Despite the increased winding (resistive) losses, the reduced eddy-current losses result in a net decrease in overall motor heating losses. The increasing controller efficiency with

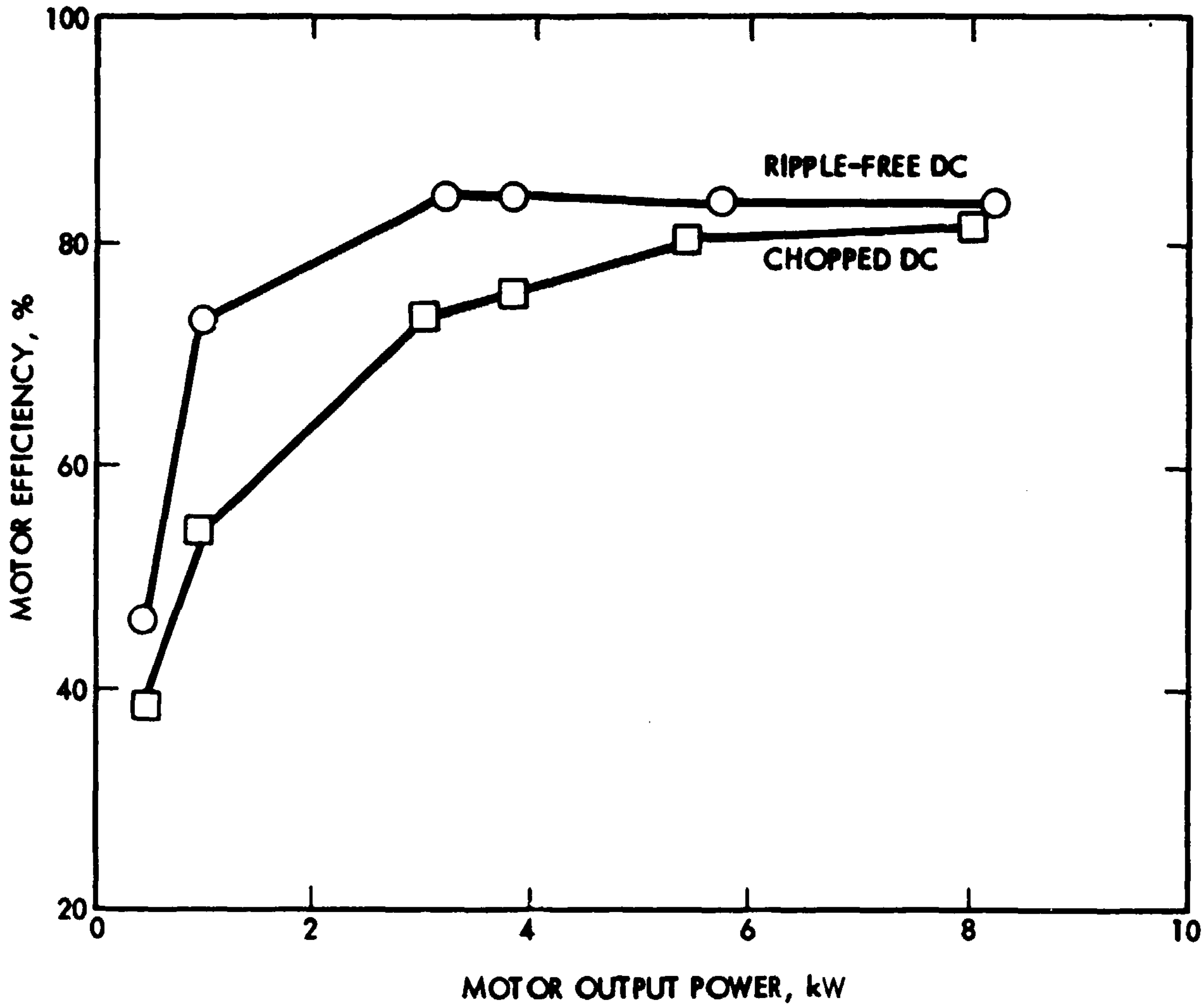


Figure 4-24. Motor Efficiency (Based on Data in Ref. 12)

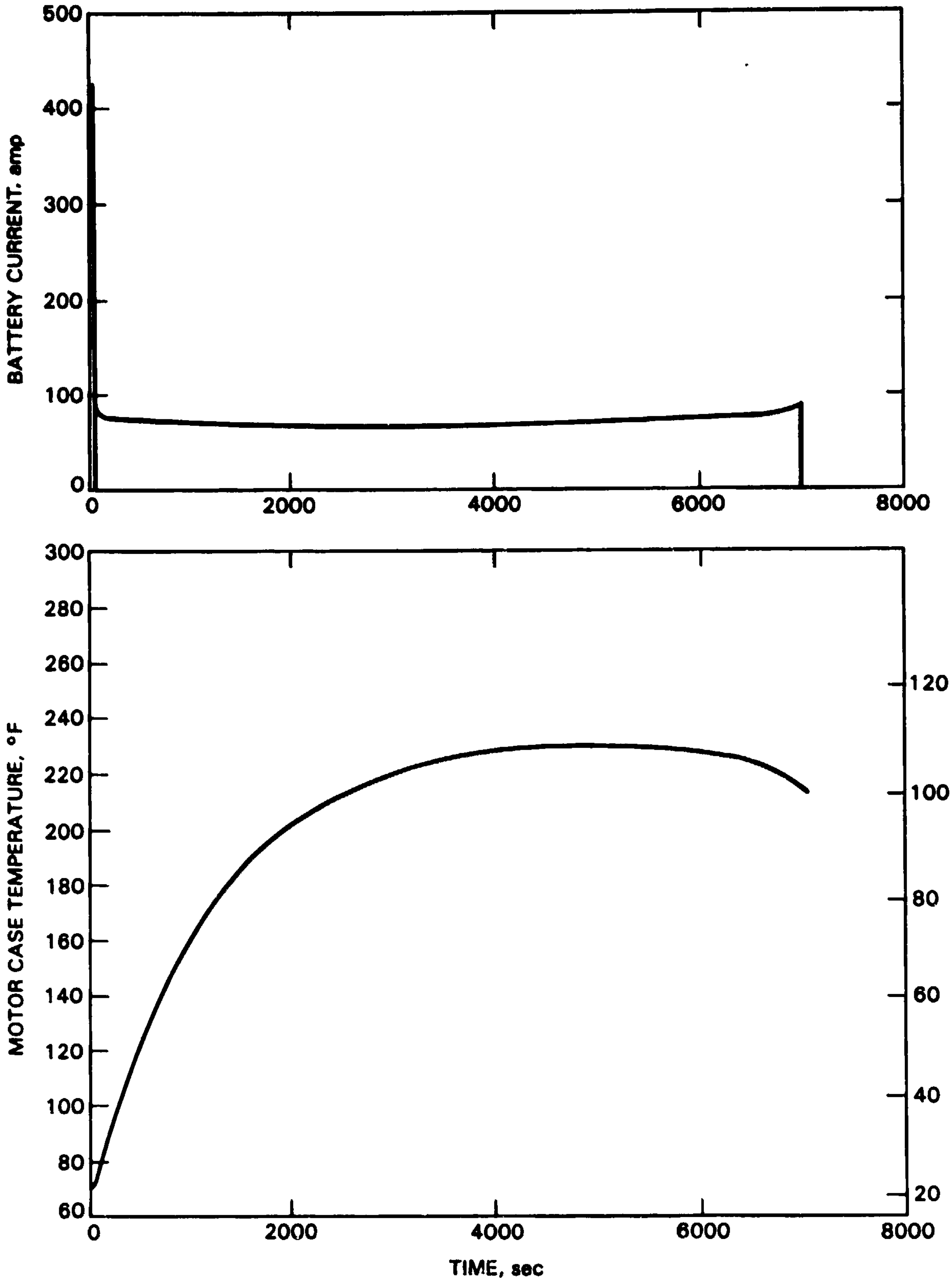


Figure 4-25. Battronic Motor Temperature and Current

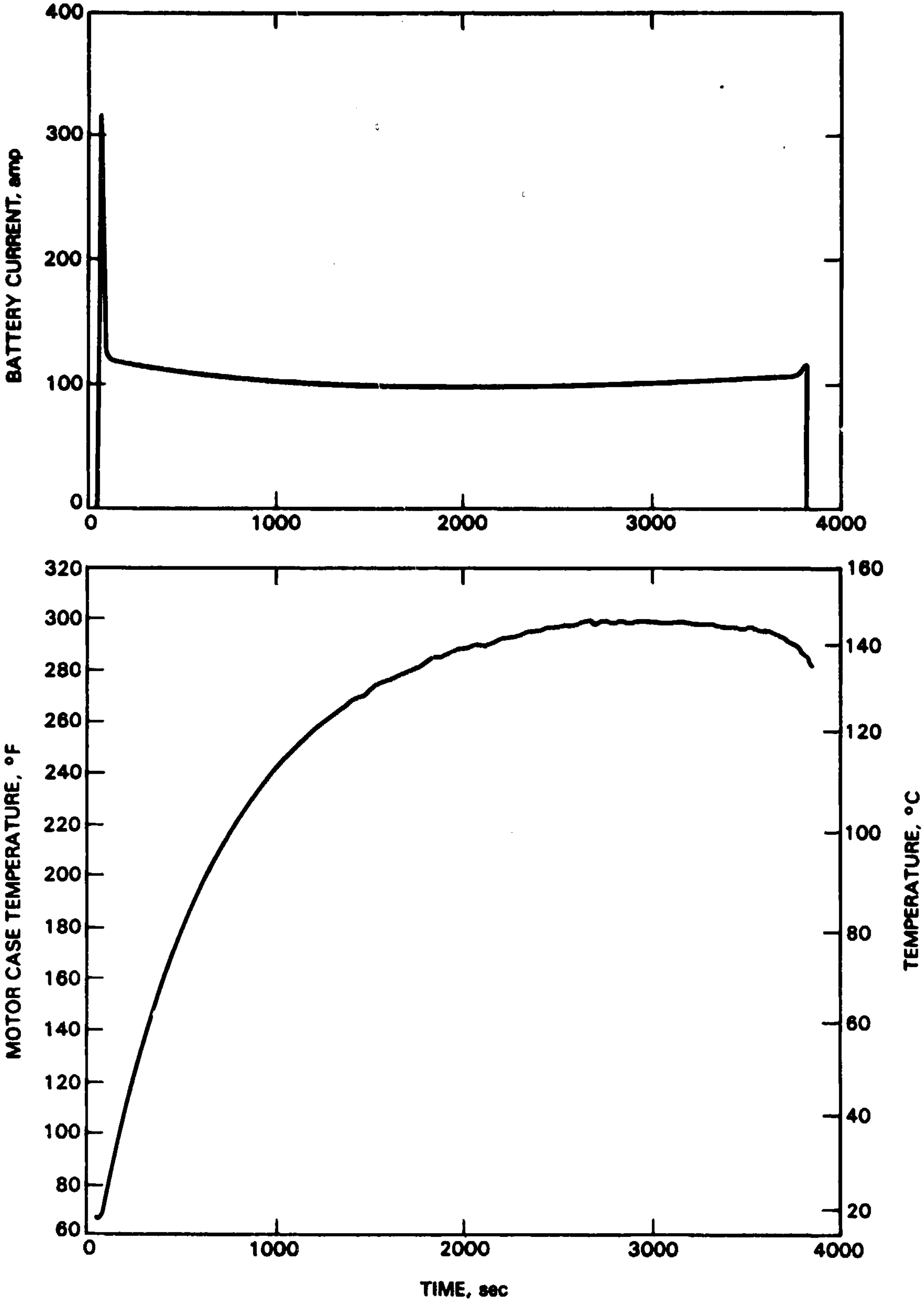


Figure 4-26. Jet Motor Temperature and Current

increasing throughputs can also be observed during the J-227a driving cycle tests. All controllers and all motors with armature choppers operated more efficiently during the acceleration mode of the driving cycle than during the cruise mode except for Jet's Schedule "B" test. The reason for the unexpected acceleration and cruise efficiencies is not obvious. The driving schedule controller efficiencies, however, presented in Figure 4-27 were derived differently from those given for the constant speed tests. During constant velocity tests, it was relatively easy to subtract out those constant power losses not directly attributable to the controller (e.g., dc-dc converter, motor fan, etc.). To segment these losses into each of the five modes of the driving schedules for each cycle completed is a considerable task which was not attempted. This shortcoming does not distract from the main objective which is to relate controller efficiency to throughput power.

Some understanding can be gained on why using an alternator was an inefficient way to charge the accessory battery for the Battronic truck. The use of the alternator requires the following relatively inefficient power conversion steps:

(1) Propulsion battery to propulsion motor,

(2) Propulsion motor to fan belt,

(3) Fan belt to alternator,

(4) Alternator to accessory battery.

These four steps compare to the single step required for a dc-dc converter. If the alternator was 100% efficient and the fan belt operated without losses, the 40 to 80% propulsion motor efficiency shown in Figure 4-24 is far less than the 90 to 95% efficiency advertised for commercial dc-dc converters. These converters are frequently used to charge the accessory battery in EVs. It is estimated that the use of an alternator resulted in accessory battery charging efficiency of 20 to 50% versus the 90 to 95% possible with dc-dc converters.

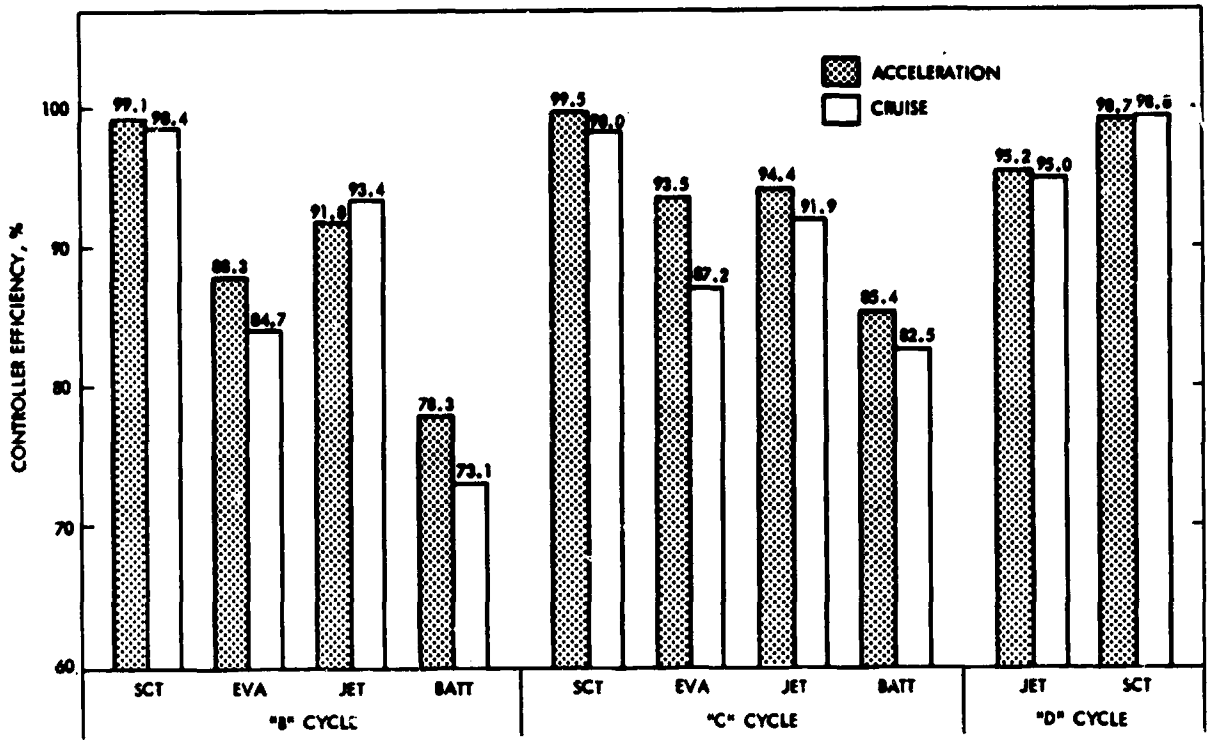


Figure 4-27. Average Controller Efficiency vs. Driving Mode for SAE J227a Cycles

SECTION V

VEHICLE/BATTERY TEST RESULTS AND BATTERY COMPARISONS

A. BASELINE TEST RESULTS

The test procedures employed in the vehicle/battery testing have been discussed in Section IV. Because of the differences in vehicle performance capabilities and time constraints of the testing program, each vehicle was tested with a slightly different set of baseline tests. Table 5-1 summarizes the sets of baseline tests performed by the 2 x 4 Vehicles. Most of these tests were performed at least twice. The average values of the vehicle/battery performance parameters are presented in this section; however, the individual results of all the dynamometer tests are listed in Appendix C.

Table 5-1. 2 x 4 Vehicle Baseline Tests Performed

	Constant Speeds, km/h (mi/h)				Driving Schedules (J227a)		
	40 (25)	56 (35)	72 (45)	88 (55)	"B"	"C"	"D"
SCT (ESB XPV-23)		●		●	●	●	●
JET (SGL 211GC-HC)		●		●	●	●	●
EVA (Varta P-125)	●	●	●		●	●	
BATT (EV-106)	●		●		●	●	

Test results of the primary test vehicle (SCT) are presented first, followed by the other 2 x 4 Vehicles. The baseline results are presented to provide background for comparison. Analysis of the results with respect to battery performance and comparisons between tests will be presented when discussing the upgrade battery results. Vehicle data analyses on component characterization and energy efficiency are presented in Section IV.

1. South Coast Technology, R-1 Electric

a. Constant Speed Range. The baseline lead-acid battery performed consistently throughout the testing period. The 56 km/h (35 mi/h) test resulted in a range of 131 km (82 mi). Range dropped to 71 km (44 mi) at 88 km/h (55 mi/h) reflecting the higher road load and lower net energy capacity of the battery at higher power levels. The battery delivered 15 kWh in the 56 km/h (35 mi/h) range test with a nominal constant power demand of 6.5 kW. The energy capacity was reduced by 24% to less than 12 kWh when tested at the higher power requirement (14 kW) of the 88 km/h (55 mi/h) tests. The results of testing the SCT vehicle at constant speeds with the baseline lead-acid battery are summarized in Table 5-1. The average vehicle energy consumption listed is calculated based on the battery output and, as such, does not include charging efficiency. The details concerning individual tests can be found in Appendix C.

b. Driving Schedule Range. The vehicle/battery performance requirements were more stringent for the driving cycle tests than the constant speed tests because of the high power demand during acceleration. The power profile required of the battery for the driving schedules was complicated somewhat because of the 4-speed transmission and individual driver technique, making exact reproduction of every cycle impossible. However, specific shift points corresponding to the manufacturer's recommendations, were employed to minimize the variations between cycles. Examples of a typical vehicle speed and battery power profiles during a J227a "D" range test are shown in Figure 5-1 to illustrate the effect the shift points had on the power profile.

The baseline lead-acid battery provided a capacity of 16.6 kWh in the J227a "B" test for a range of 76 km (47 mi). The effect of the higher average power and transient power demands in the J227a "C" and "D" schedule tests were evident in the range results. The energy consumption per kilometer in the "C" cycles was slightly less than the "B", however the battery discharged 22% less energy, producing a range of 60 km (38 mi). Though the vehicle energy consumption per kilometer in the "D" cycle was almost identical with the "B" cycle, the battery provided only 9.2 kWh and produced a range of 42 km (26 mi). Table 5-2 presents the average values of range, energy consumption, and

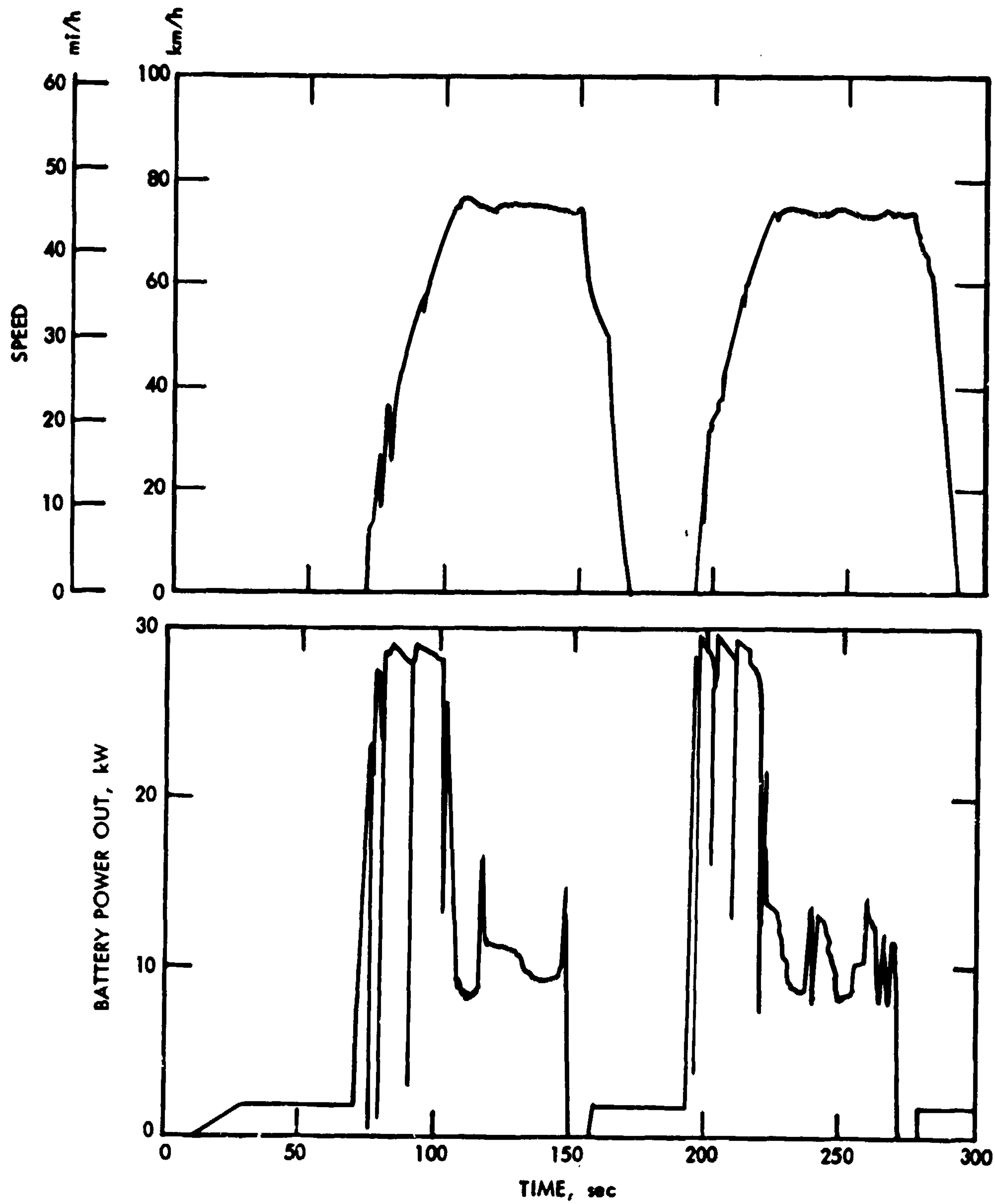


Figure 5-1. Examples of J227a "D" Driving Schedule Speed and Power - SCT Vehicle

Table 5-2. Baseline Test Results: South Coast Technology, R-1 Electric (Batteries; EV-130, Pb-A)

Constant Speed Tests

Test No.	Test Type km/h	Test Type (mi/h)	Range km	Range (mi)	Battery Discharge Energy kWh out	Battery Discharge Energy kWh in	Energy[a] Consumption Wh/km	Energy[a] Consumption (Wh/mi)	Battery Discharge Energy Density Wh/kg	Battery Discharge Energy Density (Wh/lb)	Battery Figure of Merit[b] Wh/kg	Battery Figure of Merit[b] (Wh/lb)
5,7,9	56	(35)	131.3	(81.6)	15.1	0.01	115.2	(185.4)	29.4	(13.3)	19.9	(9.0)
3,4	88	(55)	71.3	(44.3)	11.5	.02	161.4	(259.8)	22.4	(10.2)	14.2	(6.4)

Driving Schedule Results

Test No.	Test Type J227a	Cycles Driven	Range km	Range (mi)	Battery Discharge Energy kWh out	Battery Discharge Energy kWh in	Energy[a] Consumption Wh/km	Energy[a] Consumption (Wh/mi)	Battery Discharge Energy Density Wh/kg	Battery Discharge Energy Density (Wh/lb)	Battery Figure of Merit[b] Wh/kg	Battery Figure of Merit[b] (Wh/lb)
10	"B"	234	76.3	(47.4)	16.6	0.43	217.2	(349.6)	32.3	(14.6)	22.4	(10.1)
24,25	"C"	105.5	60.5	(37.6)	13.0	0.32	213.5	(343.6)	25.2	(11.4)	17.6	(8.0)
6,8	"D"	26.5	42.3	(26.3)	9.2	0.24	217.6	(350.2)	17.9	(8.1)	11.2	(5.1)

[a]Energy leaving the battery terminals.
[b]Battery figure of merit is the product of energy density and the battery's recharge energy efficiency.

battery energy output for cyclic tests. Individual test details are found in Appendix C.

2. Jet Industries, Inc., Electra Van 600

a. Constant Speed Range. The baseline lead-acid battery (SGL 211GC-HC) provided a 56 km/h (35 mi/h) range of 60 km (38 mi) with an energy output of 10.0 kWh. The energy output of the battery dropped by 26% when tested at the higher average power of the 88 km/h (55 mi/h) range test. This resulted in a range of 39 km (24 mi). Table 5-3 summarizes the results of the Jet Industries constant speed tests.

b. Driving Schedule Range. The baseline SGL battery delivered a range of 54 km (33 mi) in the "B" range test with a discharge energy of 12.4 kWh. Battery capacity dropped by 19% when discharged at the higher acceleration power levels of the "C" cycle and 52% when tested with the Jet van on the "D" cycle. The maximum range of the vehicle performing "D" cycles was affected by this strong relationship of energy capacity to power demand as shown in Table 5-3, as well as the vehicle's marginal ability to satisfy the "D" accelerations with a fully charged battery.

3. Electric Vehicle Associates, Inc., Change-of-Pace Wagon

a. Constant Speed Range. The baseline lead-acid battery (Varta P-125) produced a range of 73 km (45 mi) at 40 km/h (25 mi/h) and manifested a capacity of 14.0 kWh. Energy capacity of the battery in the 56 km/h (35 mi/h) range test dropped 13% while the vehicle energy consumption only increased 6%, demonstrating the typical discharge rate sensitivity of lead-acid batteries. Interestingly, the vehicle energy consumption rate at 72 km/h (45 mi/h) dropped slightly (see Section IV). But, the battery delivered less total energy for the 72 km/h (45 mi/h) range test and the resulting range was found

Table 5-3. Baseline Test Results: Jet Industries, Electra Van 600 (Batteries; SGL, .b-A)

Constant Speed Tests

Test No.	Test Type km/h	Test Type (mi/h)	Range km	Range (mi)	Battery Discharge Energy kWh out	Battery Discharge Energy kWh in	Energy[a] Consumption Wh/km	Energy[a] Consumption (Wh/mi)	Battery Discharge Energy Density Wh/kg	Battery Discharge Energy Density (Wh/lb)	Battery Figure of Merit[a] Wh/kg	Battery Figure of Merit[a] (Wh/lb)
10,14	56	(35)	60.0	(37.8)	10.0	0.00	163.1	(262.4)	19.0	(8.6)	11.0	(5.0)
13,15	88	(55)	39.2	(24.3)	7.4	0.00	191.5	(308.2)	14.2	(6.4)	7.8	(3.5)

Driving Schedule Results

Test No.	Test Type J227a	Cycles Driven	Range km	Range (mi)	Battery Discharge Energy kWh out	Battery Discharge Energy kWh in	Energy[a] Consumption Wh/km	Energy[a] Consumption (Wh/mi)	Battery Discharge Energy Density Wh/kg	Battery Discharge Energy Density (Wh/lb)	Battery Figure of Merit[b] Wh/kg	Battery Figure of Merit[b] (Wh/lb)
4,9	"B"	162	53.7	(33.4)	12.4	0.00	230.2	(370.5)	23.6	(10.6)	14.5	(6.5)
16,17	"C"	80	45.9	(28.5)	10.0	0.00	218.0	(350.9)	19.0	(8.6)	10.9	(4.9)
11,12	"D"	16	25.0	(15.6)	5.9	0.00	236.7	(380.9)	11.2	(5.1)	5.6	(2.5)

[a]Energy leaving the battery terminals.
[b]Battery figure of merit is the product of energy density and the battery's recharge energy efficiency.

to be 55 km (34 mi). Table 5-4 summarizes the constant speed and driving range results discussed in this section.

b. Driving Schedule Range. The EVA vehicle was incapable of satisfying the acceleration required for the J227a "D" cycle; however the J227a "B" and "C" cycles were performed successfully. The Varta batteries discharged 13.6 kWh in the "B" cycle range test, providing a range of 37 km (23 mi). The J227a "C" range was 32 km (20 mi), and the energy capacity dropped by 21% relative to the "B" cycle tests. Table 5-4 also shows these cyclic test results.

4. Battronic Truck Corp., Volta Pickup Truck

a. Constant Speed Range. The Battronic vehicle with the baseline ESB EV-106 batteries produced consistent results during the constant speed tests. During repeat tests at 40 km/h (25 mi/h), and 72 km/h (45 mi/h) range varied by less than 0.2 km in either case, with ranges of 78 km (48 mi) and 39 km (24 mi), respectively. The energy capacity of the battery dropped by 31% in the 72 km/h (45 mi/h) tests compared to the 40 km/h (25 mi/h) tests. Because the Battronic vehicle was unable to reach 88 km/h (55 mi/h), this test was not conducted. Table 5-5 summarizes the constant speed test results.

b. Driving Schedule Range. The sensitivity of the energy capacity to the power demand of the EV-106 battery was illustrated in the cyclic range tests. Energy density dropped by 33% when tested on the J227a "C" cycle relative to the J227a "B", with the resulting ranges of 47 km (18 mi) and 29 km (18 mi), respectively. The Battronic vehicle was unable to meet the acceleration requirement of the J227a "D" schedule. Table 5-5 summarizes the results of the cyclic tests.

Table 5-4. Baseline Test Results: Electric Vehicle Associates, Change-of-Pace (Batteries; Varta, Pb-A)

Constant Speed Tests

Test No.	Test Type km/h	Test Type (mi/h)	Range km	Range (mi)	Battery Discharge Energy kWh out	Battery Discharge Energy kWh in	Energy[a] Consumption Wh/km	Energy[a] Consumption (Wh/mi)	Battery Discharge Energy Density Wh/kg	Battery Discharge Energy Density (Wh/lb)	Battery Figure of Merit[b] Wh/kg	Battery Figure of Merit[b] (Wh/lb)
13,17	40	(25)	73.1	(45.4)	14.0	0.00	192.4	(309.6)	24.5	(11.1)	14.8	(6.7)
1,6	56	(35)	59.6	(37.3)	12.2	0.00	204.4	(329.0)	21.3	(9.7)	12.8	(5.8)
2,8	72	(45)	54.7	(34.0)	10.9	0.00	199.8	(321.6)	19.0	(8.6)	11.4	(5.2)

Driving Schedule Results

Test No.	Test Type J227a	Cycles Driven	Range km	Range (mi)	Battery Discharge Energy kWh out	Battery Discharge Energy kWh in	Energy[a] Consumption Wh/km	Energy[a] Consumption (Wh/mi)	Battery Discharge Energy Density Wh/kg	Battery Discharge Energy Density (Wh/lb)	Battery Figure of Merit[b] Wh/kg	Battery Figure of Merit[b] (Wh/lb)
5,9	"B"	113	37.4	(23.2)	13.6	0.00	362.3	(583.1)	23.7	(10.8)	14.5	(6.6)
4,11	"C"	56	31.9	(19.8)	10.8	0.00	338.7	(545.0)	18.8	(8.6)	11.2	(5.1)

[a]Energy leaving the battery terminals
[b]Battery figure of merit is the product of energy density and the battery's recharge energy efficiency.

Table 5-5. Baseline Test Results: Battronic Truck Corporation, Volta Pickup (Batteries, EV-106, Pb-A)

Constant Speed Tests

Test No.	Test Type km/h	Test Type (mi/h)	Range km	Range (mi)	Battery Discharge Energy kWh out	Battery Discharge Energy kWh in	Energy[a] Consumption Wh/km	Energy[a] Consumption (Wh/mi)	Battery Discharge Energy Density Wh/kg	Battery Discharge Energy Density (Wh/lb)	Battery Figure of Merit[b] Wh/kg	Battery Figure of Merit[b] (Wh/lb)
3,8	40	(25)	77.6	(48.2)	17.8	0.005	228.9	(368.3)	25.9	(11.8)	15.3	(7.0)
4,7	72	(45)	39.2	(24.4)	12.3	0.01	314.6	(506.3)	17.9	(8.1)	9.3	(4.2)

Driving Schedule Results

Test No.	Test Type J227a	Cycles Driven	Range km	Range (mi)	Battery Discharge Energy kWh out	Battery Discharge Energy kWh in	Energy[a] Consumption Wh/km	Energy[a] Consumption (Wh/mi)	Battery Energy Density Wh/kg	Battery Energy Density (Wh/lb)	Battery Figure of Merit[b] Wh/kg	Battery Figure of Merit[b] (Wh/lb)
5,9	"B"	140	46.7	(29.0)	16.8	0.19	360.3	(579.8)	24.5	(11.1)	13.4	(6.1)
6,10	"C"	52	29.4	(18.3)	11.3	0.20	383.6	(617.3)	16.4	(7.5)	6.7	(3.0)

[a]Energy leaving the battery terminals
[b]Battery figure of merit is the product of energy density and the battery's recharge energy efficiency.

B. UPGRADE TEST RESULTS

This section primarily contains the results of testing the upgrade batteries in the SCT R-1 Electric. One of the upgrade batteries underwent testing with the EVA Change-of-Pace Wagon and those results are presented as well.

As the primary test vehicle, the SCT vehicle accumulated over 7500 km (4660 mi) at JPL. The vehicle was delivered with only about 2500 km (1553 mi) on the drivetrain and improved energy consumption because of vehicle break-in was observed during the testing program. Figure 5-2 illustrates this phenomena in terms of average energy consumption. Effects of break-in caused some concern in that each of the upgrade batteries was not tested under the same conditions (i.e., discharge power). Comparisons are also complicated by the differences in battery system voltage. These effects cannot easily be deduced from the data to present a "normalized" range for direct battery comparison due to the sensitivity of battery performance to current demand. Thus, the comparisons of vehicle ranges and battery energy densities which follow are accompanied by comparisons of the power requirements of the batteries to aid in the interpretation of the battery comparisons with the baseline condition.

The results and comparisons to the baseline lead-acid battery are presented for each upgrade battery in the following sections.

1. Globe-Union Lead-Acid (EV2-13)

Figure 5-3 shows the Globe-Union (G-U) battery as it was installed in the SCT car. This battery produced a noticeable improvement over the baseline lead-acid (ESB XPV-23) in all tests, but exhibited a slightly higher decrease in energy capacity when tested at the higher power levels of the 88 km/h (55 mi/h) constant speed tests and J227a "D" driving schedules. For example, the energy capacity dropped by 27% in the 88 km/h (55 mi/h) tests versus the 56 km/h (35 mi/h) tests. This drop exceeded that exhibited by the

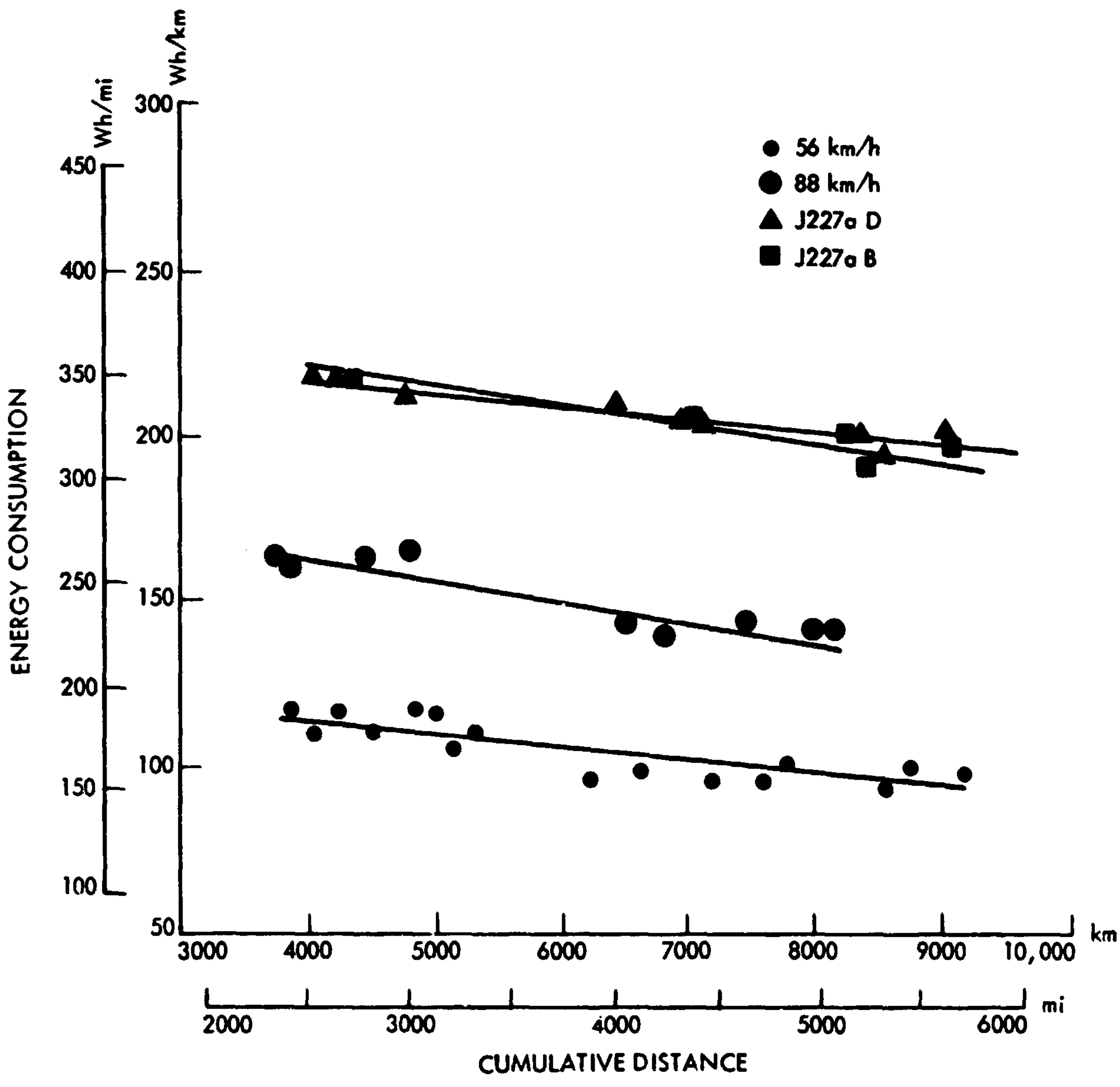


Figure 5-2. Energy Consumption of the SCT Vehicle versus Accumulated Distance Traveled

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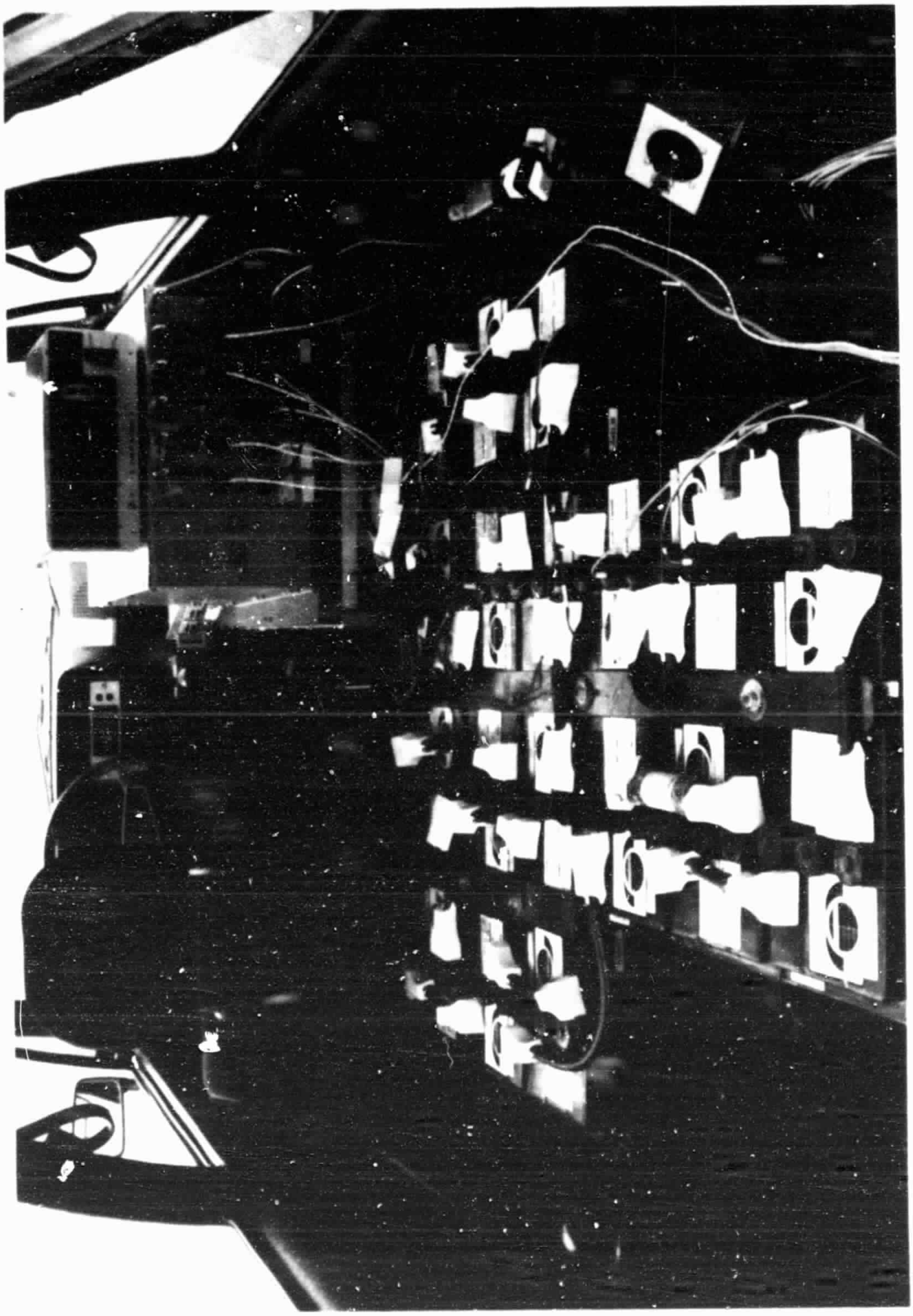

Figure 5-3. Globe Union Battery Installed in the SCT R-1 Electric

baseline lead-acid battery in the same tests (24%). However, the apparent energy density was as much as 28% greater than the baseline battery in the 56 km/h (35 mi/h) tests, and 23% greater in the 88 km/h (55 mi/h) tests. The power required from the G-U was 16% less than the baseline lead-acid in the 56 km/h (35 mi/h) tests, but only 9% less in the 88 km/h (55 mi/h) tests.

Similar results were obtained in the driving schedule range tests. The battery delivered 34 Wh/kg in the J227a "B" cycle tests, 6% greater than the baseline though the average power requirements differed by only 4%. Larger differences are observed when comparing the energy densities exhibited by the Globe-Union and baseline batteries in the J227a "D" schedule tests. The energy density of the Globe-Union battery was 34% greater than the baseline though the power requirement differed by less than 1%. Table 5-6 summarizes the SCT vehicle/Globe-Union battery results.

2. Energy Research Corporation Nickel-Zinc

The Energy Research Corporation (ERC) battery and its charger are shown in Figure 5-4. This battery substantially increased the range of the SCT vehicle at 56 km/h (35 mi/h) from 131 km (81.6 mi) to 195 km (121 mi) in the early tests, but when tested at 88 km/h (55 mi/h) the battery produced a negligible improvement over the baseline lead-acid battery. The energy capacity of the ERC battery was evidently strongly dependent on the power demand, as illustrated by the energy density drop of 37% for the 88 km/h (55 mi/h) tests versus the 56 km/h (35 mi/h) tests. Comparisons are complicated by the wide variation in test results caused by the rapidly declining battery capacity.

Performance of the ERC nickel-zinc battery was initially comparable to the baseline lead-acid in the driving schedule tests, producing a range of about 43 km (27 mi) on the "D" schedule, with an energy density of 16 Wh/kg (7.3 Wh/lb). A later "D" cycle test resulted in a range of only 26 km (16 mi) and an energy density less than 10 Wh/kg (4.5 Wh/lb), indicating that the battery was in a degraded condition. After investigating the constant speed

Table 5-6. Upgrade Test Results: South Coast Technology, R-1 Electric (Batteries; EV2-13, Pb-A)

Constant Speed Tests

Test No.	Test Type		Range		Battery Discharge Energy kWh		Energy[a] Consumption		Battery Discharge Energy Density		Battery Figure of Merit[b]	
	km/h	(mi/h)	km	(mi)	out	in	Wh/km	(Wh/mi)	Wh/kg	(Wh/lb)	Wh/kg	(Wh/lb)
39,48	56	(35)	188.3	(117.0)	18.4	0.005	97.6	(157.0)	37.6	(17.0)	27.4	(12.4)
41,43	88	(55)	88.2	(54.8)	13.5	0.01	144.0	(231.8)	27.6	(12.5)	18.5	(8.4)

Driving Schedule Results

Test No.	Test Type	Cycles Driven	Range		Battery Discharge Energy kWh		Energy[a] Consumption		Battery Discharge Energy Density		Battery Figure of Merit[b]	
	J227a		km	(mi)	out	in	Wh/km	(Wh/mi)	Wh/kg	(Wh/lb)	Wh/kg	(Wh/lb)
46,51	"B"	281	94.3	(58.6)	18.5	0.67	196.7	(316.5)	34.4	(17.1)	25.4	(12.6)
42,52	"C"	123	70.6	(43.9)	14.6	0.46	205.7	(331.1)	29.7	(13.4)	20.6	(9.3)
45,50	"D"	36	57.9	(36.0)	11.8	0.41	203.1	(326.8)	24.0	(10.9)	16.1	(7.3)

[a]Energy leaving the battery terminals
[b]Battery figure of merit is the product of energy density and the battery's recharge energy efficiency.

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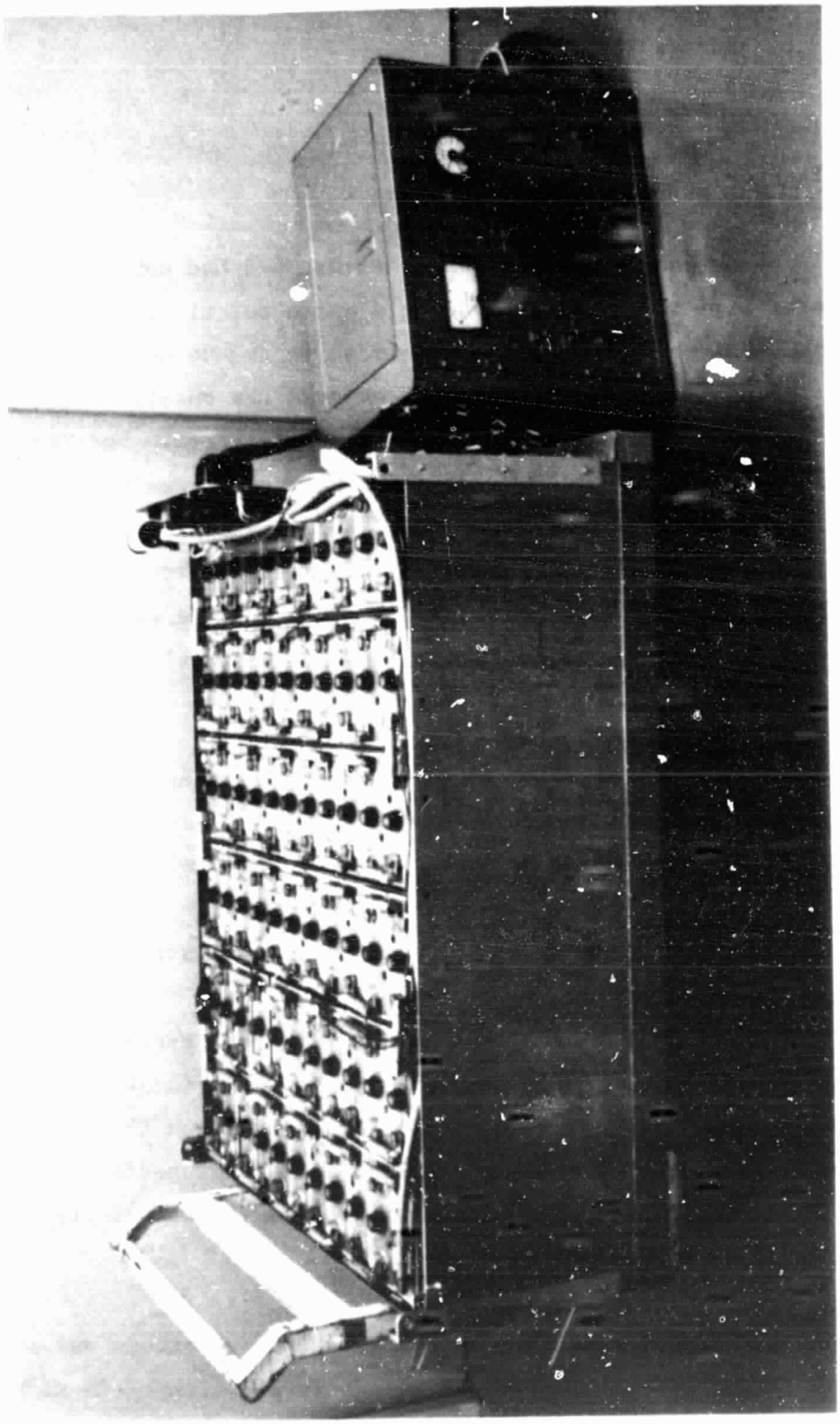

Figure 5-4. Energy Research Corporation Battery and Charger

results and the driving schedule tests, it was apparent that the battery performance continuously declined throughout the testing program and the testing was terminated after 10 charge/discharge cycles. Table 5-7 summarizes the ERC results.

3. Yardney, Inc. Nickel-Zinc

The Yardney battery shown in Figure 5-5 had substantially greater energy density than the baseline lead-acid and a relatively low sensitivity to power demand. Energy density dropped only 4% in the 88 km/h (55 mi/h) tests compared to the 56 km/h (35 mi/h) tests, whereas the baseline lead-acid battery energy density decreased 24% in comparable tests. The Yardney battery exhibited 38 Wh/kg in the 56 km/h (35 mi/h) test, 29% greater than the baseline. The power requirement for the Yardney battery was 11% less than the baseline tests because of vehicle break-in characteristics. The results were more dramatic in the 88 km/h (55 mi/h) tests where there was a 63% difference in energy density with only a 10% lower power level required of the Yardney battery.

Comparable performance was exhibited in the driving schedule range tests in which the Yardney battery demonstrated 25% and 67% greater energy densities than the baseline battery in the J227a "B" and "D" schedules, respectively. Average power requirements for the Yardney battery differed from the baseline battery by less than 11% in all the driving schedule tests.

The Yardney battery exhibited a relatively short cycle life as did the ERC nickel-zinc battery. Though the battery completed the UDV testing program with no noticeable loss in performance, in-use tests with the SCT vehicle following several months of non-use resulted in reduced performance after 22 charge/discharge cycles. Table 5-8 summarizes the results of the SCT vehicle/Yardney nickel-zinc battery tests.

The Yardney nickel-zinc battery (80 cell configuration) was also tested with the EVA Change-of-Pace Wagon in range tests at 56 km/h (35 mi/h) and over

Table 5-7. Upgrade Test Results: South Coast Technology, R-1, Electric (Batteries; ERC, Ni-Zn)

Constant Speed Tests

Test No.	Test Type km/h	Test Type (mi/h)	Range km	Range (mi)	Battery Discharge Energy kWh out	Battery Discharge Energy kWh in	Energy[a] Consumption Wh/km	Energy[a] Consumption (Wh/mi)	Battery Discharge Energy Density Wh/kg	Battery Discharge Energy Density (Wh/lb)	Battery Figure of Merit[b] Wh/kg	Battery Figure of Merit[b] (Wh/lb)
12,16 18,27	56	(35)	165.8	(103.0)	18.0	0.01	108.8	(175.1)	32.1	(14.6)	23.4	(10.6)
11,15	88	(55)	68.9	(42.8)	11.4	0.02	164.6	(265.0)	20.2	(9.2)	14.7	(6.7)

Driving Schedule Results

Test No.	Test Type J227a	Cycles Driven	Range km	Range (mi)	Battery Discharge Energy kWh out	Battery Discharge Energy kWh in	Energy[a] Consumption Wh/km	Energy[a] Consumption (Wh/mi)	Battery Discharge Energy Density Wh/kg	Battery Discharge Energy Density (Wh/lb)	Battery Figure of Merit[b] Wh/kg	Battery Figure of Merit[b] (Wh/lb)
14	"D"	27	42.8	(26.6)	9.1	0.33	212.8	(342.5)	16.2	(7.4)	11.8	(5.4)

[a]Energy leaving the battery terminals
[b]Battery figure of merit is the product of energy density and the battery's recharge efficiency.

Estimated Data: Recharge energy was not measured at JPL, so these values are based on JPL's measured Ah recharge efficiency data (87%) and ANL's recharge energy efficiency data (73%) on ERC Ni-Zn cells from the same lot as JPL's.

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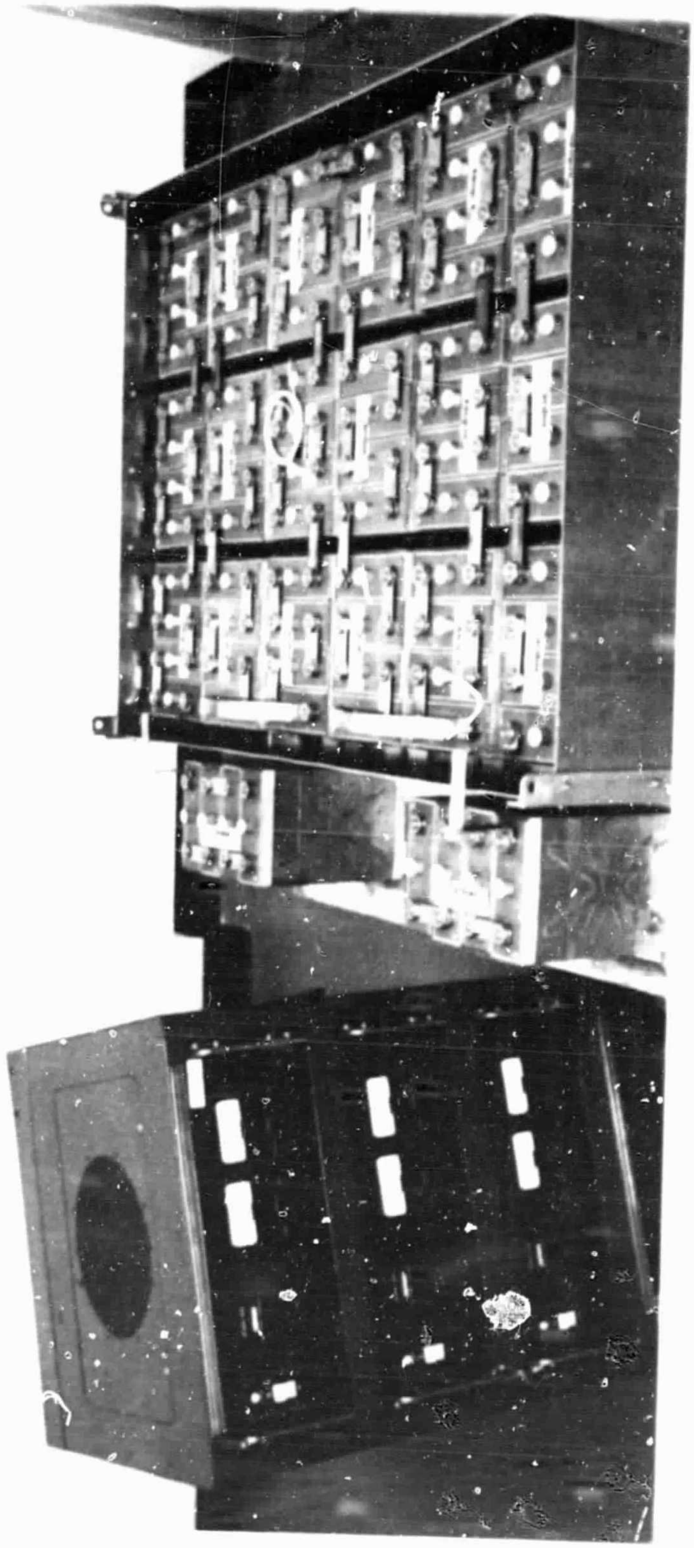

Figure 5-5. Yardney Battery and Charger

Table 5-8. Upgrade Test Results: South Coast Technology, R-1, Electric (Batteries; Yardney, Ni-Zn)

Constant Speed Tests

Test No.	Test Type km/h	Test Type (mi/h)	Range km	Range (mi)	Battery Discharge Energy kWh out	Battery Discharge Energy kWh in	Energy[a] Consumption Wh/km	Energy[a] Consumption (Wh/mi)	Battery Discharge Energy Density Wh/kg	Battery Discharge Energy Density (Wh/lb)	Battery Figure of Merit[b] Wh/kg	Battery Figure of Merit[b] (Wh/lb)
40,49, 53	56	(35)	198.6	(123.4)	20.4	0.01	102.5	(165.0)	37.9	(17.2)	28.4	(12.9)
38	88	(55)	135.0	(83.9)	19.7	0.01	145.8	(234.7)	36.5	(16.6)	27.7	(12.4)

Driving Schedule Results

Test No.	Test Type J227a	Cycles Driven	Range km	Range (mi)	Battery Discharge Energy kWh out	Battery Discharge Energy kWh in	Energy[a] Consumption Wh/km	Energy[a] Consumption (Wh/mi)	Battery Discharge Energy Density Wh/kg	Battery Discharge Energy Density (Wh/lb)	Battery Figure of Merit[b] Wh/kg	Battery Figure of Merit[b] (Wh/lb)
44	"B"	296	102.5	(63.7)	20.8	0.59	203.1	(326.8)	38.6	(17.5)	29.0	(13.1)
47	"D"	49	78.2	(48.6)	15.4	0.53	196.6	(316.4)	28.6	(13.0)	21.4	(9.8)

[a] Energy leaving the battery terminals
[b] Battery figure of merit is the product of energy density and the battery recharge energy efficiency.

Estimated Data: Recharge energy was not measured at JPL so these values are based on JPL's measured Ah recharge efficiency data (89%). The values assume that the new energy efficiency ratio to Ah efficiency for other Ni-Zn batteries is valid for the Yardney Ni-Zn battery. The resulting recharge energy efficiency is 75%.

the J227a "B" schedule. Dramatic increases in range resulted, 68% at 56 km/h (35 mi/h) and 66% on the "B" cycles as compared with the respective ranges achieved in the EVA baseline tests. Table 5-9 summarizes the EVA/Yardney results with the Change-of-Pace Wagon.

4. Westinghouse Electric Corp. Nickel-Iron

The Westinghouse battery (Figure 5-6), also showed substantial increases in energy density over the baseline lead-acid battery and relatively low sensitivity of energy density to power demand. This nickel-iron battery exhibited only a 5% drop in energy density in the 88 km/h (55 mi/h) versus 56 km/h (35 mi/h) tests (compared to a 24% drop for the baseline battery). Energy density for the 56 km/h (35 mi/h) tests was 31 Wh/kg, 5% greater than with the baseline. The battery demonstrated a 30% greater energy density than the baseline in the 88 km/h (55 mi/h) tests, even though the average power required was only 11% less.

Low energy capacity sensitivity to power demand was evident in the driving schedule tests also. The range of the SCT vehicle was increased to 100 km (62 mi) on the "B" cycle and 77 km (48 mi) on the "D", representing increases relative to the SCT baseline results of 31% and 83%, respectively. Table 5-10 summarizes the SCT/Westinghouse battery results.

5. Upgrade Battery Summary

In general, the upgrade batteries demonstrated noteworthy improvements in capacity when compared to the baseline battery. Direct comparisons are complicated by a number of factors:

(1) Various vehicles were used during the testing of the upgrade batteries, therefore the battery discharge rates were different for any given type of test.

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Table 5-9. Upgrade Test Results: Electric Vehicle Associates, Change-of-Pace (Batteries; Yardney, Ni-Zn)

Constant Speed Tests

Test No.	Test Type km/h	(mi/h)	Range km	(mi)	Battery Discharge Energy kWh out	in	Energy[a] Consumption Wh/km	(Wh/mi)	Battery Discharge Energy Density Wh/kg	(Wh/lb)	Battery Figure of Merit[b] Wh/kg	(Wh/lb)
7	56	(35)	100.4	(62.4)	20.2	0.00	201.1	(323.6)	33.7	(15.3)	25.3	(11.5)
10	72	(45)	104.3	(64.8)	22.4	0.00	215.0	(346.0)	37.4	(17.0)	28.0	(12.8)

Driving Schedule Results

Test No.	Test Type J227a	Cycles Driven	Range km	(mi)	Battery Discharge Energy kWh out	in	Energy[a] Consumption Wh/km	(Wh/mi)	Battery Discharge Energy Density Wh/kg	(Wh/lb)	Battery Figure of Merit[b] Wh/kg	(Wh/lb)
12	"B"	186	62.0	(38.5)	23.2	0.00	374.3	(602.4)	38.7	(17.6)	29.0	(13.2)
16	"C"	75	42.5	(26.4)	14.2	0.01	334.1	(537.6)	23.7	(10.8)	17.8	(8.1)

[a] Energy leaving the battery terminals

[b] Battery figure of merit is the product of energy density and the battery's recharge energy efficiency.

Estimated Data: Recharge energy was not measured at JPL so these values are based on JPL's measured Ah recharge efficiency data (89%). The values assume that the new energy efficiency ratio to Ah efficiency for other Ni-Zn batteries is valid for the Yardney Ni-Zn battery. The resulting recharge energy efficiency is 75%.

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Figure 5-6. Westinghouse Battery

Table 5-10. Upgrade Test Results: South Coast Technology, R-1, Electric (Batteries; Westinghouse, Ni-Fe)

Constant Speed Tests

Test No.	Test Type km/h	Test Type (mi/h)	Range km	Range (mi)	Battery Discharge Energy kWh out	Battery Discharge Energy kWh in	Energy[a] Consumption Wh/km	Energy[a] Consumption (Wh/mi)	Battery Discharge Energy Density Wh/kg	Battery Discharge Energy Density (Wh/lb)	Battery Figure of Merit[b] Wh/kg	Battery Figure of Merit[b] (Wh/lb)
31,36	56	(35)	182.0	(113.1)	18.2	0.01	99.6	(160.3)	30.8	(10.2)	14.5	(4.8)
30,32	88	(55)	119.6	(74.4)	17.2	0.01	143.9	(231.2)	29.2	(13.2)	13.7	(6.2)

Driving Schedule Results

Test No.	Test Type J227a	Cycles Driven	Range km	Range (mi)	Battery Discharge Energy kWh out	Battery Discharge Energy kWh in	Energy[a] Consumption Wh/km	Energy[a] Consumption (Wh/mi)	Battery Discharge Energy Density Wh/kg	Battery Discharge Energy Density (Wh/lb)	Battery Figure of Merit[b] Wh/kg	Battery Figure of Merit[b] (Wh/lb)
34	"B"	298	99.6	(61.9)	20.6	0.65	206.4	(332.2)	34.9	(15.8)	16.4	(7.4)
33,35	"D"	48.5	77.4	(48.0)	16.0	0.61	206.0	(331.6)	27.0	(12.8)	12.7	(5.8)

[a]Energy leaving the battery terminals

[b]Battery figure of merit is the product of energy density and the battery's recharge energy efficiency.

Estimated Data: Recharge energy was not measured at JPL, so these values are based on JPL's measured Ah recharge efficiency data (67%) and ANL's recharge energy efficiency data (47%) on Westinghouse cells from the same lot as JPL's.

(2) The power requirements for the SCT R-1 Electric decreased significantly with time (accumulated mileage) because of larger than expected disc brake drag (i.e., brake drag losses were initially in excess of 1.5 kW during tests with the baseline battery and gradually decayed about 0.7 kW when the Globe-Union and Yardney batteries were tested).

(3) The upgrade batteries benefited from having a higher system voltage during the Schedule "D" tests. Both the baseline and the Globe-Union lead-acid batteries were not fully discharged during this Schedule "D" testing, as the tests were terminated from a vehicle limitation rather than a battery limitation. Had these lead-acid battery systems shared the same higher nominal voltage, it is estimated that they would exhibit a 15-25% improvement in energy density despite the 10% increase in battery weight.

To minimize the effects of testing with different vehicles, only those battery tests done in conjunction with the SCT R-1 Electric are summarized here.

Figures 5-7 and 5-8 depict the average range data for the SCT vehicle during constant velocity and driving schedule tests, respectively. The effects of vehicle break-in (namely, disc-brakes) are readily observed by noting the battery discharge capacities (parenthetical numbers) above each range bar in Figure 5-7. At 56 km/h (35 mi/h) the Globe-Union, ERC, and Westinghouse batteries all exhibited capacities of 18.2 ± 0.2 kWh, yet their ranges varied from 165 km to 188 km. Although range values usually get a great deal of attention, they are not the best yardstick for comparison in the context of this report. This is especially true for the Schedule "D" tests for the previously discussed reason.

Despite the shortcomings of the range values, it can still be seen that the upgrade batteries exhibited greater capacity (range) than the baseline systems, except for the ERC battery. With all of the test results, the ERC

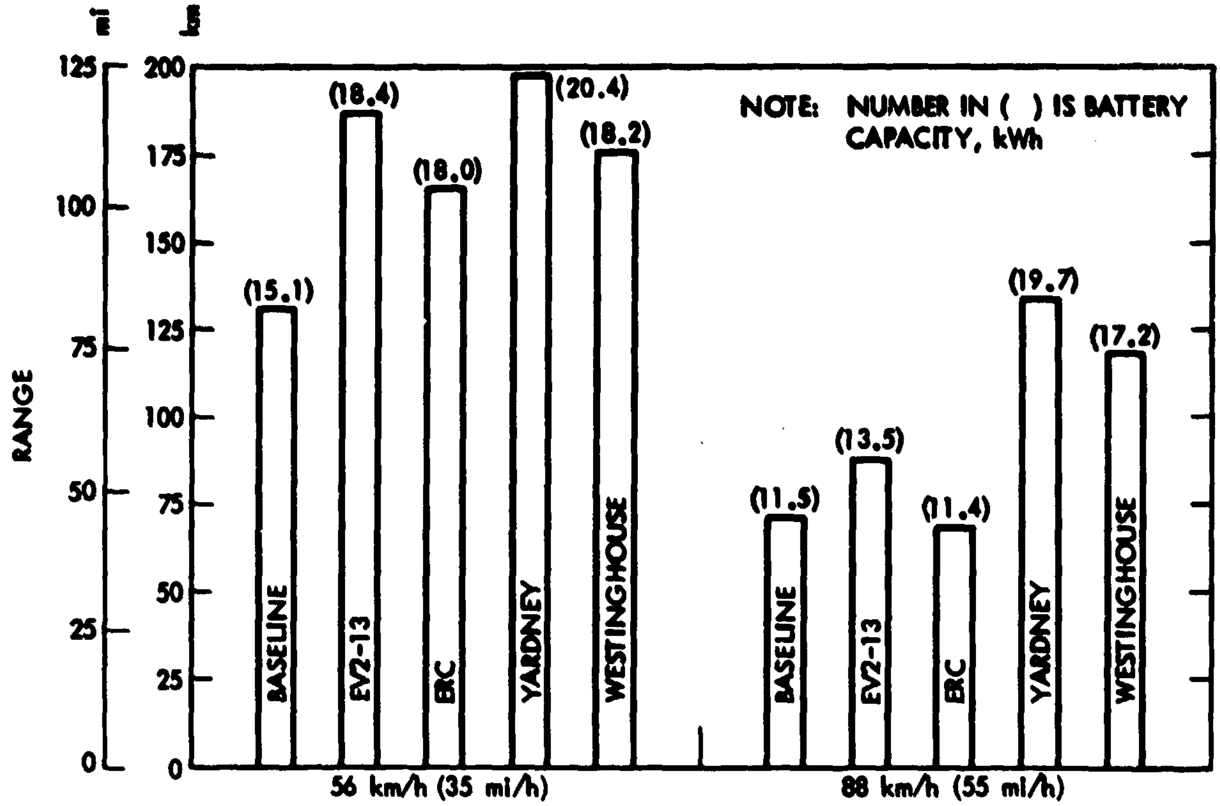

Figure 5-7. Range versus Battery, Constant Speed Tests (SCT)

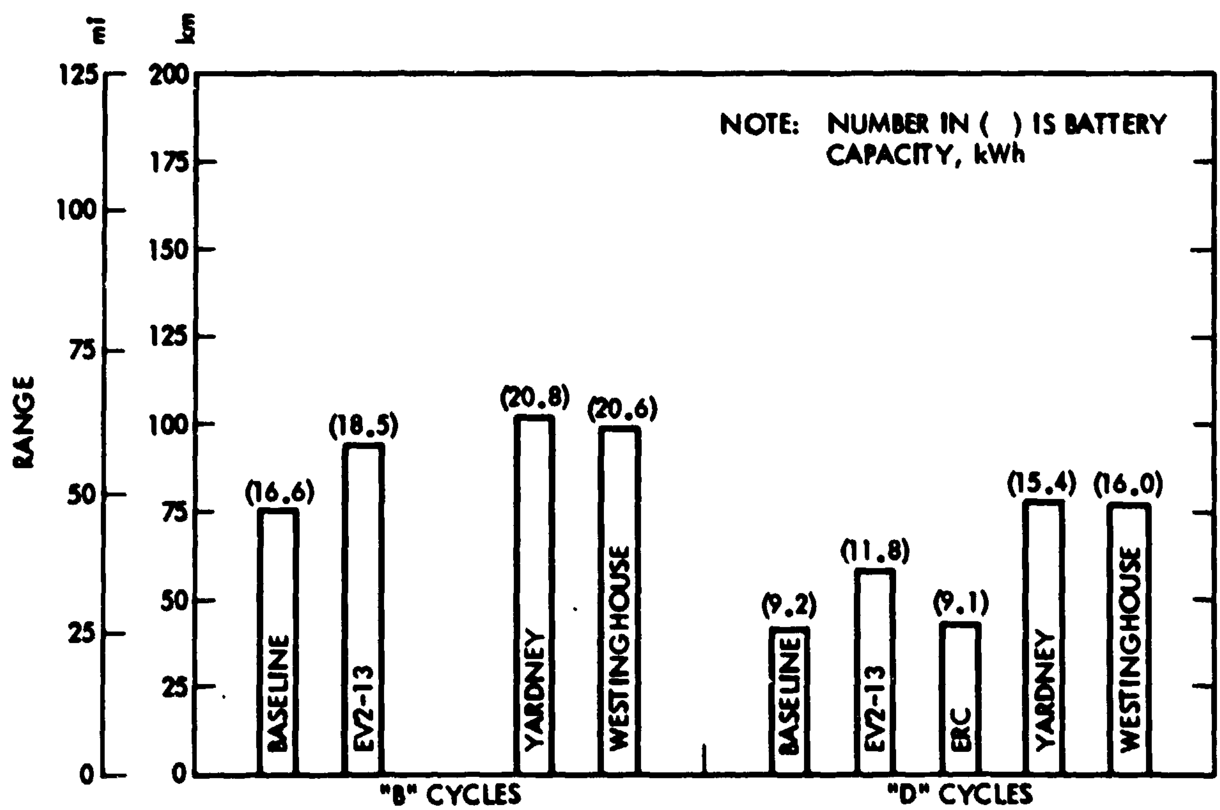

Figure 5-8. Range versus Battery, Driving Schedule Tests (SCT)

data is the average of multiple tests. However, because of the short cycle life of this battery, capacity differences from repeat tests varied by almost a factor of two. The large differences in capacity values are due to the fact that over the brief test period the capacity went from almost 100% of its rated capacity value to slightly less than 50%. If only the best of the ERC data had been presented in these figures, the ERC battery would be comparable to the Westinghouse battery in discharge capacity, but would be superior in energy density because of its lighter weight.

A better comparison of the batteries is provided in Figures 5-9 and 5-10. The comparisons of energy density factor out any differences attributable to the various battery weights and are less sensitive to the break-in effects demonstrated by the SCT car. Even here, the baseline and Globe-Union lead-acid batteries are penalized relative to the nickel batteries during the Schedule "D" tests as previously discussed.

With the exception of the qualifier for the lead-acid batteries, the energy density figures show that all of the batteries demonstrate rate (vehicle power demand) sensitivities to varying degrees. Yardney's Ni-Zn battery exhibited the smallest decline in capacity as the power requirements increased and the Westinghouse Ni-Fe battery also performed well in this aspect. A comparison between the range bar graphs and the energy density bar graphs shows that the apparent impressive improvements by the upgrade batteries shown in the range graphs are partially negated by their increased weight as reflected in the specific density graphs.

In comparing the figures for range (5-7 and 5-8) to the figures for energy density (5-9 and 5-10), it becomes apparent that the Westinghouse Ni-Fe battery was subjected to the greatest weight penalty. This weight penalty is in large part due to the auxiliary equipment needed to operate this battery. As previously indicated, JPL has estimated the weight of the electrolyte storage tank and circulation equipment to be 102 kg (224 lbs) and included this weight in the determination of energy density. Because this weight amounts to 17% of the total battery system weight, a similar percentage

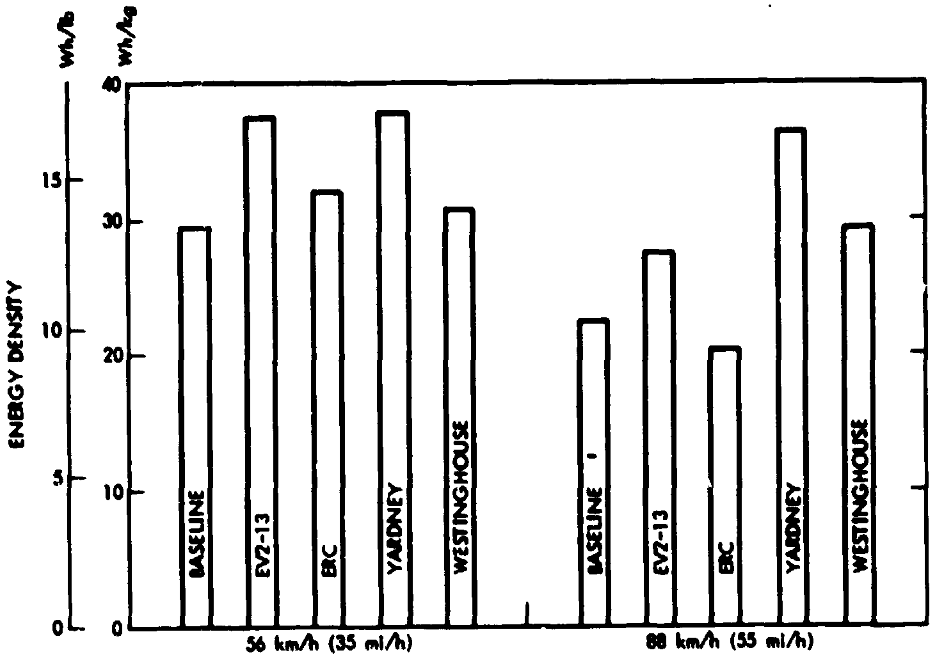

Figure 5-9. Battery Energy Density, Constant Speed Tests (SCT)

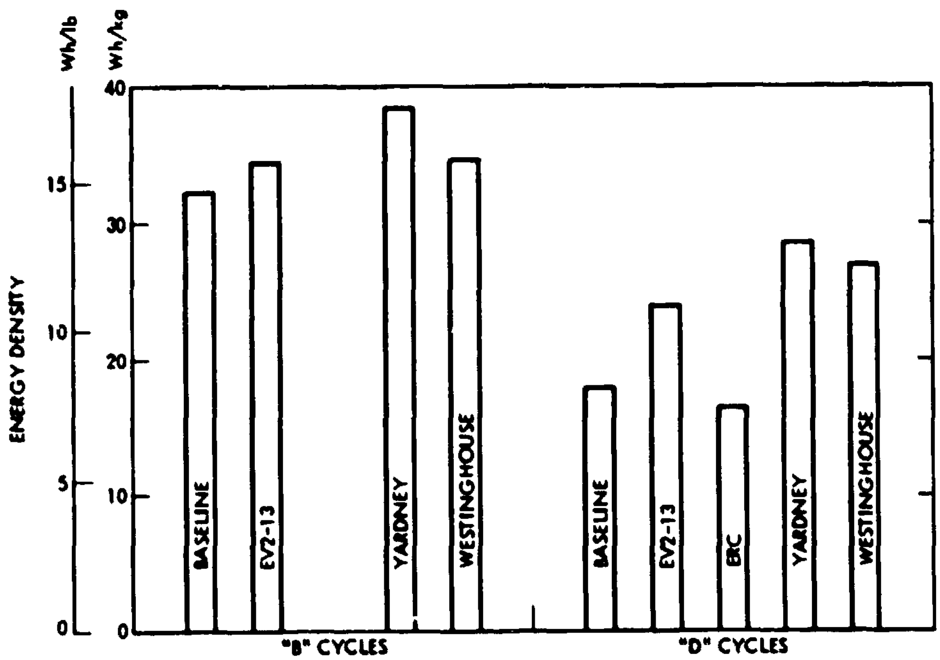

Figure 5-10. Battery Energy Density, Driving Schedule Tests (SCT)

improvement in energy density would be expected if the auxiliary hardware were excluded from the energy density calculations. However, it is unlikely that the battery could operate without the external electrolyte reservoir because of the minimal electrolyte storage capacity within each cell. It is therefore concluded that the weight of this auxiliary equipment must be factored into the energy density values presented herein.

Two final figures are shown to demonstrate the importance of battery charge efficiency. Figures 5-11 and 5-12 are presented as "battery figure-of-merit" (for lack of a better term) and were derived by multiplying the energy density values by the recharge efficiency for each specific type of test. The intent in providing the figure-of-merit data is to demonstrate that in some cases the improvement in energy density, relative to the baseline battery, is accompanied by a penalty in recharge efficiency. In other words, the increased size in fuel tank capacity (providing a greater range) has a limitation in that one must use more expensive fuel (less efficient charging).

When combined with the energy density figures, the figure-of-merit data graphically highlights the effects of charge efficiency. The relatively good recharge efficiency of the nickel-zinc batteries is evident, and the relatively poor charge efficiency for the nickel-iron battery resulted in this type of battery having a lower figure-of-merit than the baseline battery. All of the recharge data reported here is peculiar to the range test process specified in the J-227a procedure and is not necessarily indicative of the charging efficiencies to be expected under normal operation. All of the batteries tested at JPL received considerable overcharge, either as a result of the J-227a procedure or at the battery manufacturer's direction. The main emphasis was to assure maximum and repeatable battery capacity. Recharge efficiency and battery life were subordinated to the previous parameters.

All of the comparisons in this section were under discharge conditions of fairly smooth dc. The SCT R-1 Electric was the only vehicle in which all of the upgrade batteries were tested. This limitation prevents any analysis of possible effects from pulsed discharges or effects of significant levels of regenerative charging.

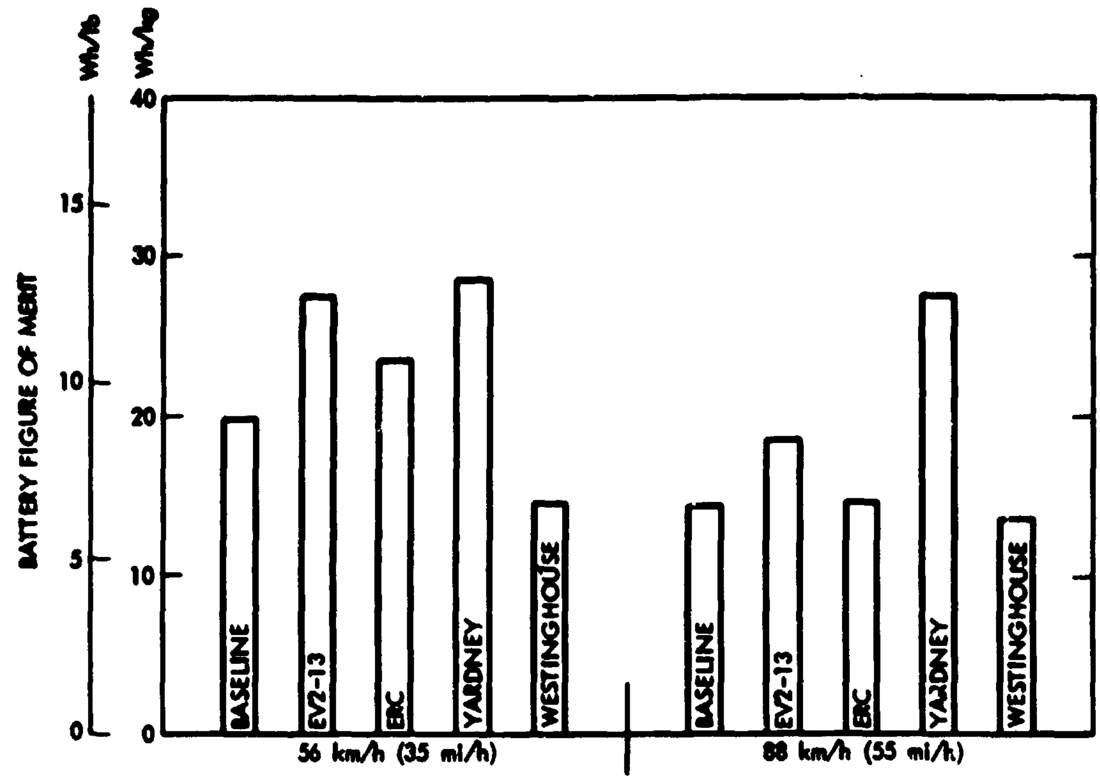

Figure 5-11. Battery "Figure-of-Merit," Constant Speed Tests (SCT)

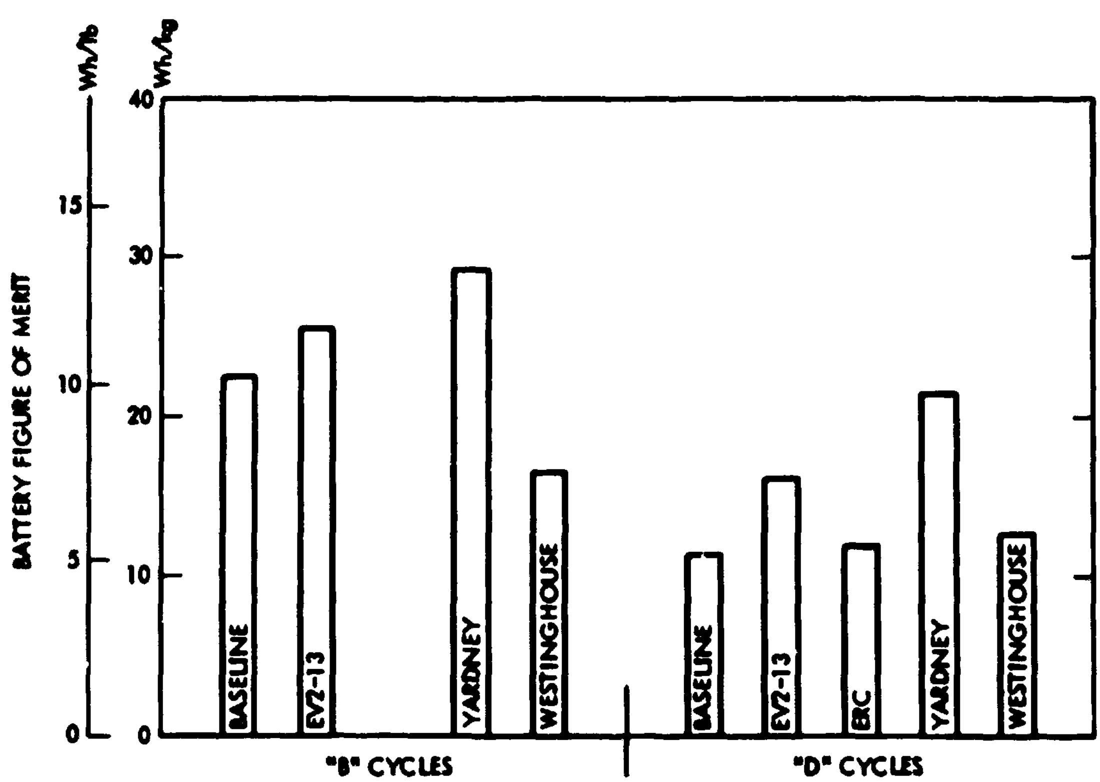

Figure 5-12. Battery "Figure-of-Merit," Driving Schedule Tests (SCT)

SECTION VI

CONCLUSIONS

The conclusions presented here are based solely on the vehicle/battery testing of the Upgraded Vehicles Task and are therefore subject to those limitations. Different types of tests under different conditions could result in different conclusions. For example, nickel-zinc batteries may demonstrate greater improvements in cycle life than other battery types under partial discharge conditions.

(1) Each of the upgrade batteries exhibited a noticeable improvement in energy density compared to the baseline battery. In the case of ERC's nickel-zinc battery, this improvement was only discernible in the first few tests.

(2) Nickel-zinc batteries, discussed in this report, exhibited good charge efficiency and good energy density. They suffered, however, from very short cycle life when configured as a full-scale battery system of the type needed to power EVs.

(3) The electrolyte management (circulation) system of the Westinghouse nickel-iron battery requires additional development before being considered for installation in a vehicle.

(4) Electrical compatibility of the upgrade batteries with vehicles exhibiting smooth discharge characteristics and little regenerative charging capability is good. Except for a single test with the Yardney nickel-zinc battery, none of the upgrade batteries were subjected to pulsed discharge. It is, therefore, impossible to make any conclusions as to battery/vehicle compatibility during pulsed operation. Conclusions on the acceptance of high charge rates available during regenerative braking or a battery's compatibility with the vehicle under such conditions cannot be made from the tests described in this report.

(5) Safety may be a concern for the nickel-iron battery. The large quantities of highly flammable gaseous effluents during charging could pose a serious problem if contained within the confines of a typical garage. Using the manufacturer's recommended charging procedure, the nickel-iron battery generates approximately 50 times as much hydrogen as does the lead-acid battery during charge. Considering the broad flammability limit of hydrogen, the potential for a fire or an explosion must be considered a serious problem unless a method is developed to reduce the quantity of hydrogen generated or to store and/or convert the hydrogen into a form which is not hazardous.

(6) Although three of the four vehicles were equipped with regenerative braking capability, none of the control systems returned significant regenerative energy to the battery. The two vehicles which added special circuitry to enable regeneration exhibited the least amount of energy returned to the battery because of other system limitations. Because of the small quantity of regenerative charging, it is questionable if the added controller complexity is justified for these specific system designs.

(7) Battery charging technology for the upgrade batteries and to a lesser degree, for the baseline batteries is not as mature as for the batteries discussed in this report. During testing of the upgrade batteries, it was not unusual for some of the battery manufacturers to change charge algorithms on a daily basis.

(8) System level engineering was scarce in the vehicles tested in this program. Because of this limitation, some of the attributes of the improved components, particularly controllers, were negated by the characteristics of the other vehicle subsystems.

SECTION VII.

RECOMMENDATIONS

The intent of the test program, documented herein, was to determine which vehicles and battery systems exhibited appropriate levels of safety, reliability, performance, and operating cost benefits for a significant EV procurement (200 vehicles) to be deployed in the Technology Demonstration Program. Although most of the systems tested by JPL satisfied at least one of the above criteria, none of them satisifed all four. As such, in September of 1979, JPL recommended that the DOE defer the 200 vehicle procurement (with upgrade batteries) for 10 months. Furthermore, some specific activities were recommended in conjunction with the 10 month deferral.

Testing was incomplete at the time the above mentioned reccommendations were made. Therefore, the following recommendations are more extensive than those initially made:

(1) The nickel-zinc batteries tested at JPL demonstrated insufficient cycle life when configured as a complete EV battery. It is recommended that vehicle system level testing of these batteries be directed toward obtaining engineering data to identify battery/vehicle compatibility problems. Until improved cycle life is attained at the cell level, the integration of more than a few nickel-zinc batteries into vehicles is not warranted.

(2) The Westinghouse nickel-iron battery shows potential for extending vehicle range and performance. Considerable effort is needed, however, to improve the electrolyte circulation system before this battery can be considered suitable for installation within a vehicle. It is recommended that additional work be done on the electrolyte circulation system, with emphasis being placed on the safe handling of the relatively large quantity of hydrogen generated during charge.

(3) Tests to evaluate the effects of pulsed discharge and regenerative charging on the nickel batteries were precluded by either the characteristics of the vehicle used to test the batteries or the short life of the battery itself. It is therefore recommended that these parameters be characterized on full-scale (vehicle size) battery systems.

(4) Vehicle limitations also precluded an analysis of the benefits of regenerative braking. A vehicle system should be developed to allow these effects to be analyzed. The safety implications of restricting braking action to only two wheels through regeneration should also be evaluated.

(5) Information on battery charging is almost nonexistent. Because charging algorithms may have a significant effect on battery life, efficiency, and safety, it is recommended that development of charging strategy be incorporated into the battery development programs.

(6) Many of the upgraded features of the 2 x 4 Vehicles failed to perform as intended because of limitations or interactions of other vehicle components. It is recommended that optimization of components or subsystems not be attempted without first determining if these improvements are compatible with the rest of the vehicle and that the optimized component does not have a negative effect on the remainder of the vehicle system.

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APPENDIX A

MANUFACTURER SPECIFICATIONS
PRODUCT IMPROVED ELECTRIC VEHICLES

Table A-1. Manufacturer Specifications

Vehicle Manufacturer	Battronic Truck Corp. Third and Walnut Streets Boyertown, PA 19512	Electric Vehicle Assoc., Inc. 9100 Bank Street Cleveland, OH 44125	Jet Industries, Inc. 2327 E. Ben White Rd. Austin, TX 78741	South Coast Technology, Inc. P.O. Box 3265 Santa Barbara, CA 93105
Vehicle Description				
Name	Volta	Change-of-Pace	Electra Van 600	R-1 Electric
Model	Pick-up Truck	Wagon	Van	3-door Hatchback
Number of Passengers	2	4	2 (option-4)	2
Vehicle Weight (pounds)				
Gross Weight	6330	4860	3390	3600
Curb Weight	5030	4200	2690	3100
Payload Weight	1000	60 (w/o passengers)	500 (w/o passengers)	100
Vehicle Size (inches)				
Wheelbase	98	100	72	94.5
Length	163-5/16	177	135.5	155.3
Width	75-3/4	77	55	63.4
Transmission Type	Dana 2-speed manual	3-speed automatic with lock-up torque converter	4-speed manual	4-speed manual
Propulsion Batteries (Lead-Acid)				
Number	24	20	17	18
Manufacturer	Electric Storage Battery	Varta	SGL Battery	Electric Storage Battery
Voltage	144	120	102	108
Ampere-Hour Capacity	144	140	138	132.5
Battery Weight (total lbs)	1512	1260	1156	1170
Controller				
Type	Silicon Controlled Rectifier	Dual Chopper	Silicon Controlled Rectifier	Transistor Chopper
Manufacturer	General Electric	Cableform	General Electric	EHV Systems
Voltage Rating	144	144	102	108
Current Rating (amps)	450	340	550	400
Weight (pounds)	90	50	47.5	32
Propulsion Motor				
Type	Series DC	Separately Excited	Series DC	DC Separately Excited
Manufacturer	Cableform	Reliance	Prestolite	Siemens
Horsepower Rating	27.5	30	22	22.8
Weight (pounds)	255	321	105	195
Body				
Type	Pick-up	Wagon	Van-Steel	Hatchback Sedan
Manufacturer	Battronic	AMC	Fuji	Volkswagen
Number of Doors (type)	2 (hinged)	3 (hinged)	3 (hinged) + 2 (sliding)	3 (hinged)
Number of Windows (type)	2 (fixed) + 2 (sliding)	4 (fixed) + 2 (roll down) + 2 (flip out)	4 (fixed) + 2 (roll down) + 2 (sliding)	4 (fixed) + 2 (roll down) + 2 (pivoting)
Number of Seats (type)	2 (bucket)	4 (bucket/bench)	2 (bench)	2 (bucket)
Cargo Volume (cubic ft)	57	50.4	81	16.5
Dimensions (inches)	69-7/8 x 73-3/4 x 26	66 x 46 x 31	77-1/2 x 47-1/2 x 38	54 x 48 x 20
Brake Type				
Front	Drum	Disc	Drum	Disc
Rear	Drum	Drum	Drum	Drum
Regenerative Braking	Yes	Yes	No	Yes
Tire Type	Steel-Belted Radial	Steel-Belted Radial	Radial	Steel-Belted Radial
Manufacturer	Firestone	Firestone	B.F. Goodrich	Continental
Size	E/P225/75R15	P-195/75/R14	155 SR 12	175/70 SR 13
Pressure (psig)	35	35	32	32 front, 35 rear
On-Board Battery Charger (Automatic Turn-off)				
Type	Ferro Resonant	Silicon Controlled Rectifier	Silicon Controlled Rectifier	Transistor
Manufacturer	Lester	EVA	Lester	SCT
Input Voltage	120/208/220	120/208/220	120/208/220	120/208/220
Peak Current (amps)	30	46	30	45
Weight (pounds)	35	30	74	15

APPENDIX B

JPL STANDARDIZED J-227a DRIVING SCHEDULES

Initial tests of electric vehicles (EVs) at JPL's Automotive Research Facility revealed a considerable degree of test-to-test variability because of the non-specificity of the widely used SAE Recommended Test Procedure. Conversations with various EV manufacturers indicated that interpretation of the driving schedules varied significantly throughout the EV industry. Because one of JPL's tasks was to evaluate improved batteries, it became imperative that all undesired variables be minimized to prevent the possibility of masking the desired battery comparisons. To assure reasonable test precision and to allow fair comparisons of these batteries, the need to "standardize" the driving schedules was a prerequisite to test initiation. Definition of specific velocity-time profiles for each of the J-227a driving schedules were established using the following basic criteria:

(1) Driving profiles should satisfy the letter of the J-227a procedures.

(2) Profiles should reflect what the "average" driver would expect to see as JPL could best identify from other established test schedules and DOE sponsored surveys of EV users.

(3) The selected profile should not specifically penalize a given EV design (i.e. resonable levels of regeneration should be allowed.)

In formulating these JPL "standardized" driving profiles, it was recognized that their characteristics may not meet with wide acceptance in the EV test community. There was no attempt, implied or otherwise, to infer that any other version of these cycles was inferior. These cycles were implemented internal to JPL solely to minimize test-to-test and driver-to-driver variability within JPL's EV test program. One of the criteria used in refining the J-227a profiles was to equate it to the "average" driver, but the resulting profiles do not reflect "average" driving. The opening statements in the SAE procedure indicates that the driving schedules were formulated only to provide a basis for comparison and were not designed to be indicative of how people actually drive. The "how people actually drive" criterion was used to temper JPL's interpretation of the basic J-227a procedure; not to modify it. Compared to test results obtained when using the Environmental Protection Agency's (EPA) urban driving schedule, delineated in the Federal Test Procedure (FTP), all of the J-227a driving schedules provide optimistic range (battery capacity) and energy economy test results.

What follows is a presentation of the "standardized" J-227a driving schedules used at JPL and brief discussion of the rationale used in defining each segment within them. With the exception of the split between "coast" and "brake" in the schedule "D" cycle, the J-227a specifications of time versus speed remain as detailed by the SAE.

"B" and "C" SCHEDULES

- Accelerations - The accelerations are an average of the acceleration profiles used in the FTP's urban driving cycle normalized to the appropriate time constraints of the J227a. This closely approximates a constant power acceleration. The primary reason for choosing this particular acceleration profile is that it represents how consumers operate their vehicles.

- Cruise - Cruise is a constant speed operation at whatever speed and for whatever duration specified in the J227a.

- Coast - The general consensus, during discussions, was that electric vehicles should coast at a rate about equal to that of conventional cars. Therefore, the "coast" appearing in the attachments reflects this thinking.

- Brake - The beginning of this phase of the driving schedules is controlled by the terminal velocity of the "coast" because the end point of the "brake" is also fixed (assuming a linear deceleration rate). Increasing the velocity at which braking is initiated (as was done by using a coast rate equal to that from conventional vehicles) dictates higher deceleration rates because the braking interval does not change. The modifications to braking, imposed by the changes in "coast", have been incorporated in the attached details of the "B" and "C" schedules.

"D" SCHEDULE

The selected "D" schedule is summarized below. Following the summary is a discussion of the considerations and rationale leading to the "coast-brake" portion for the "D" cycle.

- Acceleration - Same as in "B" and "C" Schedules above.

- Cruise - Same as in "B" and "C" Schedules.

- Coast - Coasting will be done at a rate equal to that for a conventional vehicle (i.e. the same criterion used for "B" and "C" cycles.) However, the coast time specified by the J-227a will be reduced approximately 3 seconds. This reduction will be used to extend the braking by an equal increment (thus keeping the total coast-brake time the same as called out in the J-227a). This allows the braking deceleration rate to be less than the 3.3 mi/h/s maximum rate. Coast duration will arbitrarily be limited to the closest whole second which yields a brake deceleration rate of 3.3 mi/h/s or less.

- Brake - Using the above "coast" philosophy, braking will occur at a deceleration rate of 3.17 mi/h/s. In the same manner as for the "B" and "C" cycles, braking is specified as a linear rate until the vehicle comes to a complete stop. These changes are reflected in the attached "D" Schedules.

The "coast-brake" schedule was arrived at after the following thought processes. The basic problem was as follows:

(1) If the same coast criterion as adopted for the "B" and "C" cycles is employed for the "D" cycle then the rate of braking exceeds the 3.3 mi/h/s limit, (Note that the 3.3 mi/h/s is somewhat arbitrary, but more on that later) or the total brake time is longer than allowed by J-227a if the 3.3 mi/h/s limit is observed.

(2) Observing the 3.3 mi/h/s limit leads to either a shortened coast time or a coast deceleration rate greater than chosen for the "B" and "C" cycles and greater than that observed for conventional vehicles.

A self-imposed, maximum braking rate of 3.3 mi/h/s has been assumed. It is believed that this is the same limit adopted by the EPA for the Federal Test Procedure and may reflect dynamometer limitations. A modest effort was made to verify this assumption, but was unsuccessful. However it is clear that 3.3 mi/h/s is not derived from a consideration of driver comfort and is nowhere near to the onset of skid of a vehicle. Rates somewhat higher, approximately 5 mi/h/s can be used on the dynamometer, but above that limit there is a problem with tire slippage on the dyno rolls.

Between General Motors, Ford and Chrysler, at least ten separate track test procedures exist. Although these procedures are usually not used for dynamometer testing, they do provide some guidance on "coast" and "brake". Coast is defined in all these procedures as closed throttle (CT) and typically is simply regarded as part of the braking protion of the procedure. Braking is always done linearly, at least for the procedures reviewed, unless it is a foot off the brake and foot off the throttle deceleration. Most of the procedures use multiple braking rates; the highest being 6.8 mi/h/s in the Ford Suburban cycle, and the slowest being 0.7 mi/h/s for the Crysler Interstate cycle. The average braking rate for all ten cycles is 2.8 mi/h/s which is considerably less than the 3.3 mi/h/s maximum proposed here.

Another SAE Procedure for fuel economy measurements specified all braking to be at linear rate of approximately 2.7 mi/h/s. The rationale for SAE's rate is based on a survey of actual braking rates in five major cities. Average braking, as reported by the survey, is a function of vehicle speed and varies from less than 1 mi/h/s at 45 mi/h to 3.5 mi/h/s at 8 mi/h.

All of the well known dynamometer procedures are for the purpose of exhaust emission testing. The highest braking rate is 3.4 mi/h/s in the European cycle which is only slightly faster than the 3.3 mi/h/s found in the

Federal Test Procedure. The average braking rate for these six dyno procedures is 3.1 mi/h/s.

All of the above leads to the conclusion that a brake deceleration rate of 3.3 mi/h/s is a reasonable one to choose and the rate of 4.11 mi/h/s implied for the "D" cycle was too high. A 3.3 mi/h/s rate is in reasonable agreement with what consumers really use and falls within the range of rates used in other dynamometer procedures.

Time - Speed Tables

Schedule "B"

Time (sec)	Speed (mi/h)	Time (sec)	Speed (mi/h)	Time (sec)	Speed (mi/h)
0	0.00	21	20.00	51	0.00
1	1.67	22	20.00	52	0.00
2	3.35				
3	5.03	↕	↕	↕	↕
4	6.71				
5	8.28	36	20.00	70	0.00
6	9.78	37	20.00	71	0.00
7	11.06	38*	20.00	72*	Repeat Cycle
8	12.28	39	19.20		starting at
9	13.40	40	18.60		0 sec
10	14.43	41	18.20		
11	15.36	42*	18.00		
12	16.20	43	14.40		
13	16.97	44	10.80		
14	17.65	45	7.20		
15	18.26	46*	3.60		
16	18.80	47	0.00		
17	19.26	48	0.00		
18	19.66	49	0.00		
19*	20.00	50	0.00		
20	20.00				

*Denotes transition points from one mode to another (i.e. acceleration to cruise, etc.)

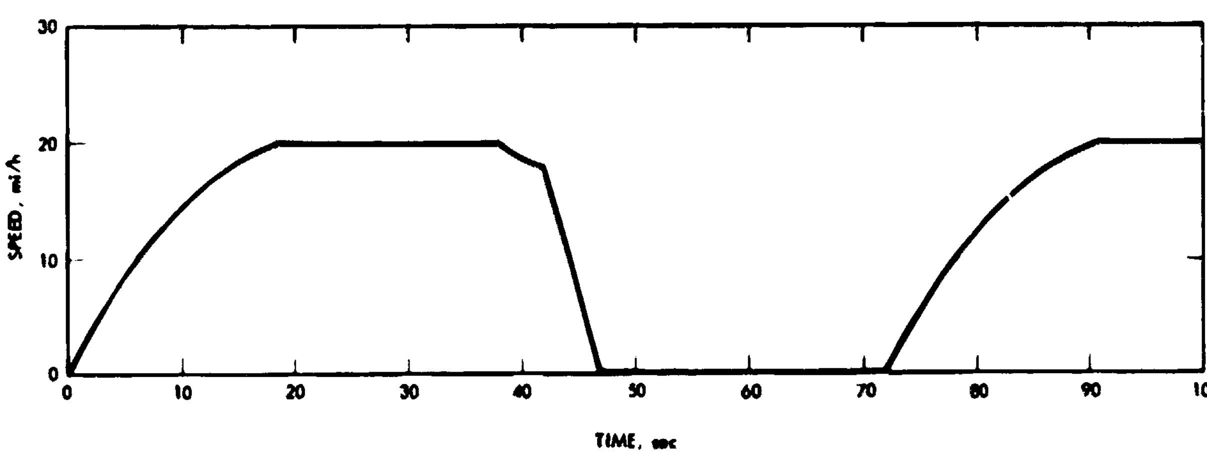

Figure B-1. SAE J227a Driving Schedule "B"

Schedule "C"

Time (sec)	Speed (mi/h)	Time (sec)	Speed (mi/h)	Time (sec)	Speed (mi/h)
0	0.00	21	30.00	54	2.89
1	2.65	↕	↕	55*	0.00
2	5.31			56	0.00
3	7.97			57	0.00
4	10.60	37	30.00	58	0.00
5	13.05	38*	30.00	59	0.00
6	15.28	39	29.19	60	0.00
7	17.33	40	28.45	↕	↕
8	19.18	41	27.89		
9	20.89	42	27.40		
10	22.43	43	26.98	78	0.00
11	23.83	44	26.59	79	0.00
12	25.08	45	26.27	80*	Repeat Cycle, starting at 0 sec
13	26.21	46*	26.00		
14	27.20	47	23.11		
15	28.07	48	20.22		
16	28.82	49	17.33		
17	29.45	50	14.44		
18*	30.00	51	11.56		
19	30.00	52	8.67		
20	30.00	53	5.78		

*Denotes transition points from one mode to another (i.e. acceleration to cruise etc.)

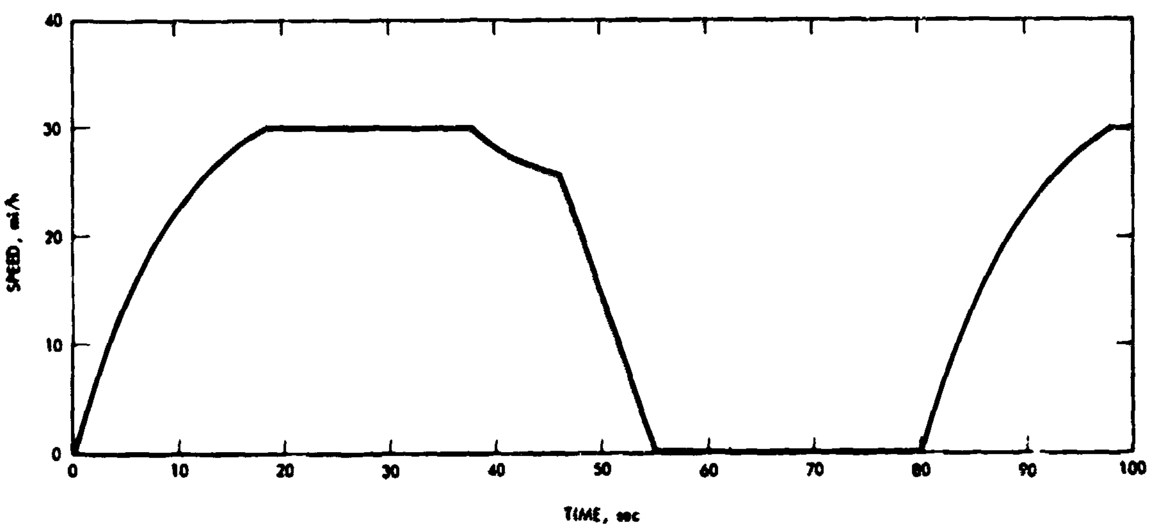

Figure B-2. SAE J227a Driving Schedule "C"

Schedule "D"

Time (sec)	Speed (mi/h)	Time (sec)	Speed (mi/h)	Time (sec)	Speed (mi/h)
0	0.0	25	43.31	91	19.00
1	2.56	26	43.93	92	15.83
2	5.12	27	44.49	93	12.67
3	7.68	28*	45.00	94	9.50
4	10.24	29	45.00	95	6.33
5	12.80	30	45.00	96	3.17
6	15.36	↕	↕	97*	0.00
7	17.79			98	0.00
8	20.08			99	0.00
9	22.24	75	45.00	100	0.00
10	24.28	76	45.00	↕	↕
11	26.20	77	45.00		
12	28.01	78*	45.00	120	0.00
13	29.72	79	43.53	121	0.00
14	31.34	80	42.33	122*	Repeat cycle Starting at 0 sec.
15	32.85	81	41.33		
16	34.27	82	40.40		
17	35.60	83	39.53		
18	36.85	84	38.73		
19	38.01	85*	38.00		
20	39.09	86	34.83		
21	40.08	87	31.67		
22	41.00	88	28.50		
23	41.85	89	25.33		
24	42.61	90	22.17		

*Denotes transition points from one mode to another (i.e. acceleration to cruise, etc.)

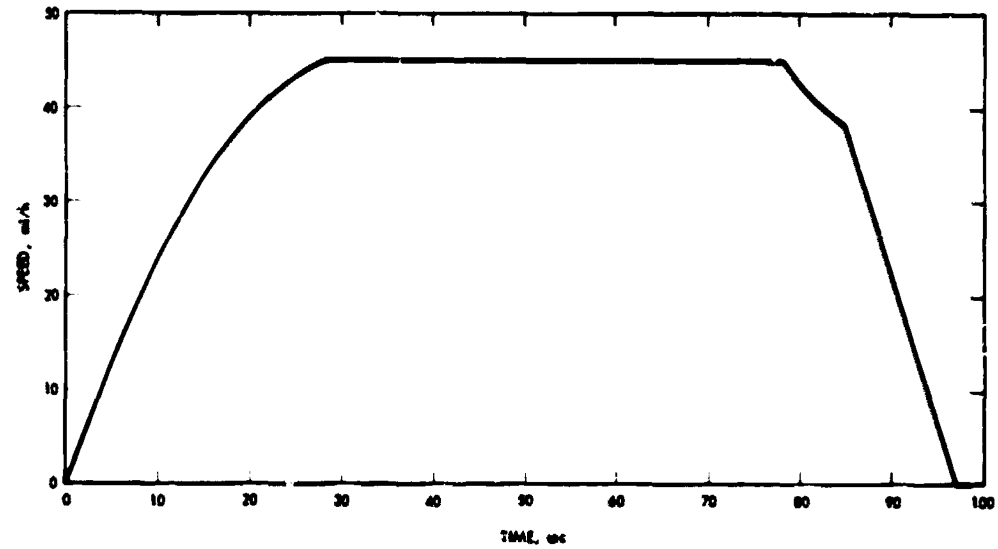

Figure B-3. SAE J227a Driving Schedule "D"

APPENDIX C

JPL VEHICLE/BATTERY SPECIFICATIONS AND TEST RESULTS

BATTRONIC TRUCK

VOLTA PICKUP

(Bat Truck)

- **Vehicle Manufacturer:**

  Battronic Truck Corporation
  Third and Walnut Streets
  Boyertown, Pennsylvania 19512

- **Vehicle Description:**

  Custom two-door Utility Truck Body, built from the ground up by Boyertown Auto Body Works

- **Vehicle Weight:**

Curb Weight	2268 kg (5000 lb)
Gross Weight	2631 kg (5800 lb)
Dyno Test Weight	2608 kg (5750 lb)

- **Vehicle Size:**

Wheelbase	2.49 m (98 in.)
Length	4.14 m (163 in.)
Width	1.92 m (76 in.)
Height	1.93 m (76 in.)
Cargo Volume	1.61 m^3 (57 ft^3)

- **Tires:**

Model	Firestone P225/75R15
Type	721 Steel-Belted Radial

BATTRONIC TRUCK (Cont'd)

- Transmission: Single Speed plus Manual Overdrive[a] (rear wheel drive)

- Propulsion Motor:

Model	General Electric 5BT-2366C10
Type	DC Traction - Series Wound
Voltage Rating	144 V
Peak Rated Power	24 kW (32 hp)

- Motor Controller, with regeneration capability:

Model	Cableform Pulsomatic Mark 10
Type	SCR
Voltage Rating	144 V
Maximum Current Rating	450 A

- Test Termination Criteria (Vehicle or other):

  Inability of vehicle to maintain specified test speed within 5%, or
  Inability of vehicle to accelerate fast enough to reach the specified cruise speed within two seconds of the specified time for J227a cycle tests, or
  Any other condition which may be deleterious to the vehicle or battery.

- Propulsion Battery (Baseline Tests):

Model	ESB (formerly Exide) EV-106
Type	Lead-Acid
Quantity	24 ea 6-V modules

[a]Gear changes only permitted when vehicle not in motion.

BATTRONIC TRUCK (Cont'd)

Rated Capacity	132.5 Ah at 75 A (125 Ah at 75 A)[b]
Nominal System Voltage	144 V
System Weight	686 kg (1512 lb)[c]

- Test Termination Criteria (Baseline Battery):

  Battery Voltage falls below 1.3 V/cell.

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[b]Downrated by Exide subsequent to JPL test.
[c]Based on battery module weight only.

BATTRONIC TRUCK
VOLTA PICKUP
(BAT TRUCK)

TEST NUMBERS	1	2	3	4	5	6	7	8
TEST DATE	02/29/80	03/03/80	03/05/80	03/07/80	03/10/80	03/12/80	03/14/80	03/17/80
TEST TYPE	C	B	25MPH	45MPH	B	C	45MPH	25MPH
BATTERY TYPE	PB-A	PB-A	PB-A	PB-A	PB-A	PB-A	PB-A	PB-A
BATTERY	EV-106	EV-106	EV-106	EV-106	EV-106	EV-106	EV-106	EV-106
BATTERY ENERGY ECONOMY (MI/KWH)	1.61	1.74	2.71	1.90	1.71	1.61	1.97	2.72
RANGE (MILES)	15.2	25.7	48.2	24.4	28.7	19.2	24.3	48.3
BATTERY DISCHARGE ENERGY (KWH)	9.46	14.81	17.79	12.28	16.78	11.91	12.30	17.77
BATTERY REGEN. ENERGY (KWH)	0.16	0.24	0.01	0.01	0.21	0.21	0.01	0.0047
BATTERY REGEN. ENERGY (%)	1.69	1.62	0.05	0.08	1.25	1.76	0.08	0.02
BATTERY DISCHARGE (AMP - HOURS)	N.A.	N.A.	142.4	100.5	144.5	102.5	101.1	140.8
BATTERY REGEN. (AMP - HOURS)	0.0	0.0	0.0	0.1	0.9	1.1	0.1	0.0
BATTERY REGEN. AMPERAGE (%)	0.0	0.0	0.0	0.1	0.6	1.0	0.1	0.0
ARMATURE INPUT ENERGY (KWH)	7.86	11.40	13.48	11.12	12.74	9.76	10.95	13.24
ARMATURE REGEN. OUTPUT (KWH)	0.33	0.37	0.01	0.02	0.43	0.45	0.02	0.01
ARMATURE REGEN. OUTPUT (%)	4.3	3.2	0.1	0.2	3.4	4.6	0.2	0.1
FIELD ENERGY (KWH)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
CONTROLLER EFFICIENCY (%)	83.0	76.9	75.7	90.5	78.9	81.9	89.0	74.5
ODOMETER READING (MILES)	683.1	700.1	720.5	782.8	809.5	866.1	889.4	915.8
BATTERY RECHARGE ENERGY EFFICIENCY(%)	47.83	50.38	58.05	51.35	53.84	50.94	53.14	60.86
BATTERY RECHARGE AMPERAGE EFFICIENCY(%)	N.A.	N.A.	76.3	70.4	70.6	72.6	72.1	77.6
BATTERY TEMP. BEFORE (DEG F)	71.2	68.8	70.0	65.0	71.8	72.2	74.0	73.2
BATTERY TEMP. AFTER (DEG F)	108.8	107.2	92.6	92.4	105.0	103.2	102.0	96.8

* COMMENTS

BATTRONIC TRUCK (Cont'd)

TEST NUMBERS	9	10	11
TEST DATE	03/19/80	03/21/80	03/24/80
TEST TYPE	B	C	C
BATTERY TYPE	PbA	PbA	PbA
BATTERY	EV-106	EV-106	EV-106
BATTERY ENERGY ECONOMY (MI/KWH)	1.78	1.63	1.64
RANGE (MILES)	24.2	17.4	17.1
BATTERY DISCHARGE ENERGY (KWH)	10.76	10.72	10.40
BATTERY REGEN. ENERGY (KWH)	0.17	0.19	0.18
BATTERY REGEN. ENERGY (%)	1.01	1.77	1.72
BATTERY DISCHARGE (AMP - HOURS)	142.5	92.3	91.1
BATTERY REGEN. (AMP - HOURS)	0.2	0.9	0.9
BATTERY REGEN. AMPERAGE (%)	0.2	1.0	1.0
ARMATURE INPUT ENERGY (KWH)	12.50	8.81	8.65
ARMATURE REGEN. OUTPUT (KWH)	0.40	0.39	0.39
ARMATURE REGEN. OUTPUT (%)	3.2	4.4	4.5
FIELD ENERGY (KWH)	N.A.	N.A.	N.A.
CONTROLLER EFFICIENCY (%)	74.8	82.2	82.7
ODOMETER READING (MILES)	969.0	1002.2	1021.7
BATTERY RECHARGE ENERGY EFFICIENCY(%)	55.39	30.50	0.00
BATTERY RECHARGE AMPERAGE EFFICIENCY(%)	77.0	44.9	N.A.
BATTERY TEMP. BEFORE (DEG F)	48.2	69.6	70.4
BATTERY TEMP. AFTER (DEG F)	103.4	103.2	104.4

* COMMENTS

TEST NO. 10: BATTERIES #2 AND #7 LOSING CAPACITY LOW RECHARGE EFFICIENCY DUE TO CHARGER FAILURE (TIMER)

TEST NO. 11: ENGINEERING DATA NOT REDUCED - PARITY ERRORS - BATTERIES DYING

ELECTRIC VEHICLE ASSOCIATES (EVA)
CHANGE-OF-PACE
(EVA PACER)
(EVAP)

- **Vehicle Manufacturer:**

  Electric Vehicle Associates
  9100 Bank Street
  Cleveland, Ohio 41125

- **Vehicle Description:**

  Converted 1978 AMC Pacer Station Wagon

- **Vehicle Weight:**

Curb Weight	1996 kg (4400 lb)
Gross Weight	2268 kg (5000 lb)
Dyno Test Weight	2268 kg (5000 lb)

- **Vehicle Size:**

Wheelbase	2.54 m (100 in.)
Length	4.49 m (177 in.)
Width	1.95 m (77 in.)
Height	NA
Cargo Volume	1.42 m^3 (50.4 ft^3)

- **Tires:**

Model	Firestone P195/75/R14
Type	Steel-Belted Radial

- Transmission:

  Three-Speed Automatic with lock-up torque converter (rear-wheel drive)

- Propulsion Motor:

Model	Reliance
Type	DC Traction, Separately Excited, Compound
Voltage	120 V
Peak Rated Power	22.4 kW (30 hp)
Continuous Rated Power	13.4 kW (18 hp)

- Motor Controller (armature and field) with Regeneration Capability:

Model	Cableform, Pulsomatic Mark 10
Type	SCR (armature) and Transistor (field)
Voltage Rating	144 V
Maximum Current Rating	340 A

- Test Termination Criteria (Vehicle or Other):

  Inability of vehicle to maintain specified test speed within 5%, or
  Inability of vehicle to accelerate fast enough to reach the specified cruise speed within 2 s of the specified time for J227a cyclic tests, or
  Any other condition which may be deleterious to the vehicle or battery.

- **Propulsion Battery (Baseline Tests):**

Model	Varta P-125
Type	Lead-Acid
Quantity	20 ea 6-V modules
Rated Capacity	160 Ah at C/3 or 156 Ah at 75 A
Nominal System Voltage	120 V
System Weight	572 kg (1260 lb)[d]

- **Test Termination Critieria (Baseline Battery):**

Battery voltage falls below 1.3 V cell

- **Propulsion Battery (Yardney Ni-Zn):**

Model	Yardney
Type	Nickel-Zinc
Quantity	80 ea 1.625-V cells
Rated Capacity	250 Ah at C/3 (83 A)
Nominal System Voltage	130 V
System Weight	599 kg (1320 lb)[e]

- **Test Termination Criteria (Yardney Battery):**

Battery voltage falls below 1.3 V/cell when current is above 83 A, or
Battery voltage falls below 1.25 V/cell when current is below 83 A.

Note - Unless otherwise indicated, all range (battery discharge) tests were conducted within 1 hour of charge termination. If testing could not be started within 1 hour of charge termination, the battery received a top-off charge to compensate for self-discharge.

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[d]Battery weight only, excludes 18 kg (40 lb) of cables for module interconnections.

[e]Based on average weight of 3 each, 4-cell modules including cell interconnections and hardware holding the 4-cell module together.

ELECTRIC VEHICLE ASSOCIATES (EVA)
CHANGE -OF-PACE
(EVA PACER)
(EVAP)

TEST NUMBERS	1	2	3	4	5	6	7	8
TEST DATE	11/14/79	11/16/79	11/19/79	11/21/79	11/26/79	11/28/79	11/29/79	11/30/79
TEST TYPE	35MPH	45MPH	25MPH	C	B	35MPH	35MPH	45MPH
BATTERY TYPE	PB-A	PB-A	PB-A	PB-A	PB-A	PB-A	NI-ZN	PB-A
BATTERY	VARTA	VARTA	VARTA	VARTA	VARTA	VARTA	YARDNEY	VARTA
BATTERY ENERGY ECONOMY (MI/KWH)	3.03	3.10	2.96	1.83	1.71	3.05	3.09	3.12
RANGE (MILES)	35.3	33.0	37.6	20.2	22.4	38.7	62.4	35.0
BATTERY DISCHARGE ENERGY (KWH)	11.7	10.6	12.7	11.0	13.1	12.7	20.2	11.2
BATTERY REGEN. ENERGY (KWH)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BATTERY REGEN. ENERGY (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BATTERY DISCHARGE (AMP - HOURS)	105.4	96.5	113.7	104.0	119.0	114.3	177.0	101.6
BATTERY REGEN. (AMP - HOURS)	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0
BATTERY REGEN. AMPERAGE (%)	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0
ARMATURE INPUT ENERGY (KWH)	9.76	9.78	9.67	9.23	9.91	10.51	16.53	10.23
ARMATURE REGEN. OUTPUT (KWH)	0.00	0.01	0.16	0.11	0.19	0.00	0.00	0.00
ARMATURE REGEN. OUTPUT (%)	0.0	0.1	1.7	1.2	2.0	0.0	0.0	0.0
FIELD ENERGY (KWH)	0.640	0.308	1.022	0.553	0.948	0.742	1.194	0.330
CONTROLLER EFFICIENCY (%)	89.6	94.9	84.5	88.8	83.1	88.8	87.8	94.2
ODOMETER READING (MILES)	2776.4	2819.7	2857.5	2912.2	2935.4	2961.2	3005.6	3077.2
BATTERY RECHARGE ENERGY EFFICIENCY(%)	60.96	59.46	60.88	59.37	59.09	63.15	N.A.	60.80
BATTERY RECHARGE AMPERAGE EFFICIENCY(%)	76.9	75.9	76.3	78.6	74.5	79.1	N.A.	77.1
BATTERY TEMP. BEFORE (DEG F)	71.4	69.6	67.7	72.0	67.3	73.2	72.8	73.2
BATTERY TEMP. AFTER (DEG F)	84.0	82.1	81.9	88.1	88.4	84.0	99.8	84.0

* COMMENTS

EVA PACER (Cont'd)

TEST NUMBERS	9	10	11	12	13	14	15	16
TEST DATE	12/03/79	12/04/79	12/05/79	12/06/79	12/07/79	12/11/79	02/15/80	02/19/80
TEST TYPE	B	45MPH	C	B	25MPH	C	25MPH	C
BATTERY TYPE	PB-A	NI-ZN	PB-A	NI-ZN	PB-A	NI-ZN	PB-A	NI-ZN
BATTERY	VARTA	YARDNEY	VARTA	YARDNEY	VARTA	YARDNEY	VARTA	YARDNEY
BATTERY ENERGY ECONOMY (MI/KWH)	1.72	2.89	1.84	1.66	0.0	0.00	0.00	1.86
RANGE (MILES)	24.1	64.6	19.5	38.5	44.2	0.0	0.0	26.4
BATTERY DISCHARGE ENERGY (KWH)	14.0	22.4	10.6	23.2	0.0	0.0	0.0	14.2
BATTERY REGEN. ENERGY (KWH)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
BATTERY REGEN. ENERGY (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BATTERY DISCHARGE (AMP - HOURS)	125.9	184.5	99.4	185.3	126.7	0.0	0.0	122.6
BATTERY REGEN. (AMP - HOURS)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BATTERY REGEN. AMPERAGE (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ARMATURE INPUT ENERGY (KWH)	10.47	19.37	8.78	16.68	10.54	0.00	0.00	11.67
ARMATURE REGEN. OUTPUT (KWH)	0.16	0.00	0.10	0.28	0.00	0.00	0.00	0.17
ARMATURE REGEN. OUTPUT (%)	1.5	0.0	1.2	1.7	0.0	0.0	0.0	1.4
FIELD ENERGY (KWH)	1.007	1.063	0.520	1.875	1.173	0.000	0.000	0.851
CONTROLLER EFFICIENCY (%)	82.2	91.0	87.7	79.9	99.9	0.0	0.0	88.2
ODOMETER READING (MILES)	3117.3	3145.0	3219.2	3241.6	3285.8	0.0	0.0	3929.2
BATTERY RECHARGE ENERGY EFFICIENCY(%)	63.56	N.A.	59.48	N.A.	N.A.	N.A.	N.A.	N.A.
BATTERY RECHARGE AMPERAGE EFFICIENCY(%)	76.9	N.A.	77.5	N.A.	80.6	N.A.	N.A.	N.A.
BATTERY TEMP. BEFORE (DEG F)	70.2	74.8	73.2	75.8	73.4	N.A.	N.A.	71.4
BATTERY TEMP. AFTER (DEG F)	88.0	104.7	91.5	85.8	87.4	N.A.	N.A.	98.6

* COMMENTS

TEST NO. 12: MISSED 1 CYCLE - TEST OK

TEST NO. 13: ERD & ERI MEASUREMENT FAILED DURING TEST

TEST NO. 14: INVALID RANGE TEST (CONTACTOR FAILURE)

TEST NO. 15: INVALID RANGE TEST (WRONG DYNO SETTING)

EVA PACER (Cont'd)

TEST NUMBERS	17	18
TEST DATE	08/20/80	01/21/80
TEST TYPE	25MPH	25MPH
BATTERY TYPE	PB-A	NI-ZN
BATTERY	VARTA	YARDNEY
BATTERY ENERGY ECONOMY (MI/KWH)	3.25	2.06
RANGE (MILES)	46.7	20.8
BATTERY DISCHARGE ENERGY (KWH)	14.4	10.1
BATTERY REGEN. ENERGY (KWH)	0.00	0.00
BATTERY REGEN. ENERGY (%)	0.0	0.0
BATTERY DISCHARGE (AMP - HOURS)	128.2	82.3
BATTERY REGEN. (AMP - HOURS)	0.0	0.0
BATTERY REGEN. AMPERAGE (%)	0.0	0.0
ARMATURE INPUT ENERGY (KWH)	10.97	7.55
ARMATURE REGEN. OUTPUT (KWH)	0.00	0.00
ARMATURE REGEN. OUTPUT (%)	0.0	0.0
FIELD ENERGY (KWH)	1.318	0.986
CONTROLLER EFFICIENCY (%)	85.6	84.9
ODOMETER READING (MILES)	3559.4	3613.1
BATTERY RECHARGE ENERGY EFFICIENCY(%)	62.06	N.A.
BATTERY RECHARGE AMPERAGE EFFICIENCY(%)	77.5	N.A.
BATTERY TEMP. BEFORE (DEG F)	69.0	69.4
BATTERY TEMP. AFTER (DEG F)	85.2	81.2

* COMMENTS
TEST NO. 18: INVALID RANGE TEST (CONTROLLER FAILED)

JET INDUSTRIES

ELECTRA VAN 600

(Jet Van)

- **Vehicle Manufacturer:**

  Jet Industries, Inc
  7101 Burleson Road
  Austin, Texas 78760

- **Vehicle Description:**

  Converted Fuji Mini Van (Subaru 600 Mini Van)

- **Vehicle Weight:**

Curb Weight	1270 kg (2800 lb)
Gross Weight	1542 kg (3400 lb)
Test Weight	1531 kg (3375 lb)

- **Vehicle Size:**

Wheelbase	1.83 m (72 in.)
Length	3.43 m (135 in.)
Width	1.40 m (55 in.)
Height	1.59 m (62 in.)
Cargo Volume	2.14 m^3 (75.6 ft^3)

- **Tires:**

Model	Pirelli - 155 SR12
Type	Steel-Belted Radial

- **Transmission:**

  Four-speed manual transaxle (rear wheel drive)

- **Propulsion Motor:**

Model	Prestolite Model MTC
Type	DC Traction, Series Wound
Voltage Rating	102 V
Peak Rated Power	21 kW (28 hp)
Continuous Rated Power	NA

- **Motor Controller, no regeneration capability:**

Model	General Electric EV-1
Type	SCR
Voltage Rating	102 V
Maximum Current Rating	550 A

- **Test Termination Criteria (Vehicle and other):**

Inability of vehicle to maintain specified test speed within 5%, or
Inability of vehicle to accelerate fast enough to reach the specified cruise speed within 2 s of the specified time for J227a cyclic tests, or
Any other condition which may be deleterious to the vehicle or battery.

- **Propulsion Battery (Baseline Tests):**

Model	SGL 211GC-HC
Quantity	17 ea 6-V modules
Type	lead-acid
Rated Capacity	138 Ah at C/3 (46 A)
Nominal System Voltage	102 V
System Weight	524 kg (1156 lb)[f]

- **Test Termination Criteria (Baseline Battery):**

  Battery voltage falls below 1.3 V/cell.

[f]Based on weight of battery modules only.

JET INDUSTRIES
ELECTRA VAN 600
(JET VAN)

TEST NUMBERS	1	2	3	4	5	6	7	8
TEST DATE	06/29/79	07/02/79	07/05/79	07/13/79	07/16/79	08/09/79	10/23/79	10/24/79
TEST TYPE	COAST	B	B	B	35MPH	35MPH	35MPH	45MPH
BATTERY TYPE	PH-A	PB-A	PB-A	PB-A	PB-A	PB-A	PB-A	PB-A
BATTERY	SGL	SGL	SGL	SGL	SGL	SGL	SGL	SGL
BATTERY ENERGY ECONOMY (MI/KWH)	N.A.	2.64	2.69	2.75	3.61	3.71	N.A.	N.A.
RANGE (MILES)	N.A.	13.4	25.7	33.8	14.2	20.5	N.A.	35.4
BATTERY DISCHARGE ENERGY (KWH)	N.A.	5.06	9.6	12.29	3.93	7.69	N.A.	N.A.
BATTERY REGEN. ENERGY (KWH)	0.00	0.014	0.00	0.22	0.008	0.0007	0.00	0.00
BATTERY REGEN. ENERGY (%)	0.0	2.76	0.0	1.79	0.20	0.00909	0.0	0.0
BATTERY DISCHARGE (AMP - HOURS)	N.A.	55.9	104.3	139.2	43.7	85.1	N.A.	N.A.
BATTERY REGEN. (AMP - HOURS)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BATTERY REGEN. AMPERAGE (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ARMATURE INPUT ENERGY (KWH)	N.A.	4.73	8.93	11.37	3.68	7.07	N.A.	N.A.
ARMATURE REGEN. OUTPUT (KWH)	0.00	0.033	0.00	0.10	0.0201	0.004	0.00	0.00
ARMATURE REGEN. OUTPUT (%)	0.0	0.0	0.0	0.87	0.0	0.0	0.0	0.0
FIELD ENERGY (KWH)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
CONTROLLER EFFICIENCY (%)	N.A.	93.4	93.3	92.5	93.0	91.9	N.A.	N.A.
ODOMETER READING (MILES)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
BATTERY RECHARGE ENERGY EFFICIENCY(%)	N.A.	47.58	56.73	61.50	N.A.	N.A.	N.A.	N.A.
BATTERY RECHARGE AMPERAGE EFFICIENCY(%)	N.A.	64.5	73.9	122.5	N.A.	N.A.	N.A.	N.A.
BATTERY TEMP. BEFORE (DEG F)	N.A.	71.3	72.1	74.4	72.6	79.0	76.6	93.8
BATTERY TEMP. AFTER (DEG F)	N.A.	80.0	88.8	92.8	80.4	93.4	N.A.	N.A.

* COMMENTS

TEST NO. 1: DATA NOT APPLICABLE

TEST NO. 2: INVALID RANGE TEST (MOTOR OVERHEATED)

TEST NO. 3: INVALID RANGE TEST (CONTROLLER OVERHEATED)

TEST NO. 4: FIRST VALID RANGE TEST

TEST NO. 5: INVALID RANGE TEST (MOTOR OVERHEATED)

TEST NO. 6: INVALID RANGE TEST (CONTROLLER OVERHEATED)

TEST NO. 7: INVALID RANGE TEST, NO IDAC DATA, DIAG. TEST ONLY

TEST NO. 8: INVALID RANGE TEST, NO IDAC DATA, DIAG. TEST ONLY

JET VAN (Cont'd)

TEST NUMBERS	9	10	11	12	13	14	15	16
TEST DATE	01/11/80	01/14/80	01/16/80	01/18/80	01/21/80	01/23/80	01/25/80	01/28/80
TEST TYPE	H	35MPH	D	D	55MPH	35MPH	55MPH	C
BATTERY TYPE	PB-A	PB-A	PB-A	PB-A	PB-A	PB-A	PB-A	PB-A
BATTERY	SGL	SGL	SGL	SGL	SGL	SGL	SGL	SGL
BATTERY ENERGY ECONOMY (MI/KWH)	2.65	3.05	2.52	2.74	3.24	3.77	3.25	2.85
RANGE (MILES)	33.0	39.1	13.1	18.0	23.1	36.6	25.5	27.7
BATTERY DISCHARGE ENERGY (KWH)	12.44	10.15	5.19	6.56	7.12	9.71	7.84	9.71
BATTERY REGEN. ENERGY (KWH)	0.01	0.003	0.00	0.00	0.00	0.0002	0.00	0.06
BATTERY REGEN. ENERGY (%)	0.08	0.02	0.0	0.0	0.0	0.002	0.0	0.61
BATTERY DISCHARGE (AMP - HOURS)	137.8	116.6	58.7	75.2	79.5	109.4	86.9	113.8
BATTERY REGEN. (AMP - HOURS)	0.004	0.0	0.0	0.0	0.0	0.004	0.0	0.0
BATTERY REGEN. AMPERAGE (%)	0.002	0.0	0.0	0.0	0.0	0.003	0.0	0.0
ARMATURE INPUT ENERGY (KWH)	11.41	9.44	4.93	6.20	6.87	8.89	7.56	9.12
ARMATURE REGEN. OUTPUT (KWH)	0.02	0.0004	0.0004	0.00	0.00	0.00	0.00	0.005
ARMATURE REGEN. OUTPUT (%)	0.17	0.004	0.008	0.0	0.0	0.0	0.0	0.05
FIELD ENERGY (KWH)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
CONTROLLER EFFICIENCY (%)	91.7	93.0	94.9	94.5	96.4	91.5	96.4	93.9
ODOMETER READING (MILES)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
BATTERY RECHARGE ENERGY EFFICIENCY(%)	61.44	57.48	47.95	51.86	53.71	58.64	56.60	56.22
BATTERY RECHARGE AMPERAGE EFFICIENCY(%)	78.8	77.4	65.4	70.4	71.6	77.5	74.1	77.1
BATTERY TEMP. BEFORE (DEG F)	71.0	70.4	74.8	70.6	65.8	71.2	74.0	67.6
BATTERY TEMP. AFTER (DEG F)	88.9	87.6	88.6	88.8	82.2	90.2	90.4	92.4

* COMMENTS

JET VAN (Cont'd)

TEST NUMBERS	17
TEST DATE	01/30/80
TEST TYPE	C
BATTERY TYPE	PB-A
BATTERY	8GL
BATTERY ENERGY ECONOMY (MI/KWH)	2.85
RANGE (MILES)	29.3
BATTERY DISCHARGE ENERGY (KWH)	10.28
BATTERY REGEN. ENERGY (KWH)	0.006
BATTERY REGEN. ENERGY (%)	0.05
BATTERY DISCHARGE (AMP - HOURS)	118.0
BATTERY REGEN. (AMP - HOURS)	0.0
BATTERY REGEN. AMPERAGE (%)	0.0
ARMATURE INPUT ENERGY (KWH)	9.53
ARMATURE REGEN. OUTPUT (KWH)	0.002
ARMATURE REGEN. OUTPUT (%)	0.02
FIELD ENERGY (KWH)	N.A.
CONTROLLER EFFICIENCY (%)	92.7
ODOMETER READING (MILES)	N.A.
BATTERY RECHARGE ENERGY EFFICIENCY(%)	58.62
BATTERY RECHARGE AMPERAGE EFFICIENCY(%)	78.1
BATTERY TEMP. BEFORE (DEG F)	71.2
BATTERY TEMP. AFTER (DEG F)	96.2

* COMMENTS

SOUTH COAST TECHNOLOGY (SCT)

R-1 ELECTRIC

(SCT-RABBIT)

(SCT-1)

- **Vehicle Manufacturer:**

  South Coast Technology, Inc.
  15001 Commerce Drive
  Dearborn, Michigan 48120

- **Vehicle Description:**

  Converted 1978 Volkswagen Rabbit

- **Vehicle Weight:**

Curb Weight	1424 kg (3140 lb)
Gross Weight	1633 kg (3600 lb)
Dyno Test Weight	1644 kg (3625 lb)

- **Vehicle Size:**

Wheelbase	2.4 m (94.5 in.)
Length	3.9 m (155 in.)
Width	1.6 m (63.4 in.)
Height	1.4 m (55.5 in.)
Cargo Volume	NA

- **Tires:**

Model	Continental 175/70 SR13
Type	Steel-belted Radial

SCT-1 (Cont'd)

- **Transmission:**

  Four-speed Manual Transaxle (front wheel drive)

- **Propulsion Motor:**

Motor	Siemens 1GK1-161Z
Type	DC Traction, Separately Excited
Voltage Rating	130 V
Peak Rated Power	35 kW (45.6 hp)
Continuous Rated Power	17 kW (22.8 hp)

- **Motor Controller (field only) with Regeneration Capability:**

Model	EHV Systems, EHV-1
Type	Transistor (field only)
Voltage Rating	108 V nominal
Maximum Current Rating	300 A (armature), 25 A (field chopper)

- **Test Termination Criteria (Vehicle and other):**

  Inability of vehicle to maintain specified test speed within 5%, or
  Inability of vehicle to accelerate fast enough to reach the specified cruise speed within 2 s of the specified time for J227a cyclic tests, or
  Any other condition which may be deleterious to the vehicle or battery.

- **Propulsion Battery (Baseline tests):**

Model	ESB (Exide) EV-130[g]
Type	Lead-Acid
Quantity	18 ea 6-V modules
Rated Capacity	162.5 Ah at 75 A[h]
Nominal System Voltage	108 V
System Weight	514 kg (1134 lb)[i]

- **Test Termination Criteria (baseline battery):**

Battery Voltage falls below 1.3 V/ cell.

Note - After test #63 SCT-1 was modified by changing the motor and transmission, at which time it was redesignated as SCT-1A

- Propulsion Battery (Yardney Ni-Zn):

Model	Yardney
Type	Nickel-Zinc
Quantity	72 ea 1.625-V cells
Rated Capacity	250 Ah at C/3 (83 A)
Nominal System Voltage	119 V
System Weight	539 kg (1188 lb)[j]

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[g] Later designated XPV-23.
[h] Later downrated to 155 Ah at 75 A
[i] Based on battery module weight only.
[j] Based on average weight of 3 each 4-cell modules including cell interconnections and hardware holding the 4-cell module together.

- **Test Termination Criteria (Yardney Battery):**

  Battery Voltage falls below 1.3 V/cell when current is above 83 A,

  or

  Battery Voltage falls below 1.25 V/cell when current is below 83 A.

  Note - Unless otherwise indicated, all range (battery discharge) tests were conducted within 1 hour of charge termination. If testing could not be started within 1 hour of charge termination, the battery received a top-off charge to compensate for self-discharge.

- **Propulsion Battery (ERC Ni-Zn):**

Model	Energy Research Corp, NiZn
Type	Nickel-Zinc
Quantity	66 ea. 1.625-V cells
Rated Capacity	250 Ah at C/3 (83 A)
Nominal System Voltage	108 V
System Weight	561 kg (1236 lb)[k]

- **Test Termination Criteria (ERC Battery):**

  Battery Voltage falls below 1 V/cell.

  Note - Unless otherwise indicated, all range (battery discharge) tests were conducted within 1 hour of charge termination. If testing could not be started within 1 hour of charge termination, the battery received a top-off charge to compensate for self-discharge.

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[k]Based on the weight of one of the six each 11-cell modules, including all cell interconnects and hardware holding the 11-cell string together. Weight of the module interconnects are excluded.

- **Propulsion Battery (Westinghouse Ni-Fe)**

Model	Westinghouse Ni-Fe
Type	Nickel-Iron
Quantity	90 ea 1.33-V cells
Rated Capacity	220 Ah at 75 A
Nominal System Voltage	120 V
System Weight	590 kg (1300 lb)[1]

- **Test Termination Criteria (Westinghouse Battery):**

Battery Voltage falls below 1.0 V/cell, or
Various cell voltage criteria established by on-site Westinghouse representative, none of which were below the average battery voltage equivalent to 1.0 V/cell.

Note - Unless otherwise indicated, all range (battery discharge) tests were conducted within 15-20 minutes of charge termination.

[1]Battery system weight is based on the measured weight of 10 cells and an estimated weight for an electrolyte management system which includes: hoses, circulation pump, electrolyte storage tank and 40 liters of stored electrolyte. These estimated weights are based on weights of a system shipped to JPL in January 1981.

SOUTH COAST TECHNOLOGY (SCT)
R-1 ELECTRIC
(SCT-RABBIT)
(SCT-1)

TEST NUMBERS	1	2	3	4	5	6	7	8
TEST DATE	05/09/79	05/14/79	05/31/79	06/04/79	06/06/79	06/09/79	06/11/79	06/13/79
TEST TYPE	55MPH	55MPH	55MPH	55MPH	35MPH	D	35MPH	D
BATTERY TYPE	PB-A	PB-A	PB-A	PB-A	PB-A	PB-A	PB-A	PB-A
BATTERY	EV-130	EV-130	EV-130	EV-130	EV-130	EV-130	EV-130	EV-130
BATTERY ENERGY ECONOMY (MI/KWH)	4.09	3.86	3.83	3.87	5.27	2.85	5.57	2.86
RANGE (MILES)	49.9	45.7	44.8	43.8	79.5	25.8	84.8	26.8
BATTERY DISCHARGE ENERGY (KWH)	12.18	11.85	11.70	11.32	15.08	9.04	15.22	9.37
BATTERY REGEN. ENERGY (KWH)	0.01	0.01	0.02	0.01	0.01	0.24	0.01	0.24
BATTERY REGEN. ENERGY (%)	0.08	0.08	0.17	0.08	0.06	2.65	0.06	2.56
BATTERY DISCHARGE (AMP - HOURS)	123.0	119.7	118.7	114.1	149.9	91.9	152.4	94.2
BATTERY REGEN. (AMP - HOURS)	0.0	0.1	0.1	0.0	0.0	1.6	0.3	1.7
BATTERY REGEN. AMPERAGE (%)	0.0	0.1	0.1	0.0	0.0	1.8	0.2	1.9
ARMATURE INPUT ENERGY (KWH)	11.91	11.56	11.46	11.07	14.09	8.56	14.29	8.88
ARMATURE REGEN. OUTPUT (KWH)	0.07	0.01	0.02	0.01	0.01	0.27	0.01	0.27
ARMATURE REGEN. OUTPUT (%)	0.6	0.1	0.2	0.1	0.1	3.1	0.1	3.0
FIELD ENERGY (KWH)	N.A.	0.098	0.012	0.081	0.664	0.451	0.835	0.390
CONTROLLER EFFICIENCY (%)	97.7	98.3	98.0	98.5	97.8	99.6	99.3	98.9
ODOMETER READING (MILES)	2155.3	N.A.	2328.0	2372.6	2416.0	2495.4	2581.2	2605.8
BATTERY RECHARGE ENERGY EFFICIENCY(%)	N.A.	50.98	61.39	64.98	65.75	63.75	69.19	61.76
BATTERY RECHARGE AMPERAGE EFFICIENCY(%)	79.6	68.2	79.5	81.4	81.4	79.5	84.2	79.6
BATTERY TEMP. BEFORE (DEG F)	82.5	75.8	73.8	72.2	72.3	72.3	76.4	75.2
BATTERY TEMP. AFTER (DEG F)	94.9	91.3	90.7	88.6	78.1	72.6	85.8	80.4

* COMMENTS

TEST NO. 1: INVALID RANGE TEST, BIAS PLY TIRES & BAD MOTOR DO NOT REPORT

TEST NO. 2: INVALID RANGE TEST, BIAS PLY TIRES AND BAD MOTOR DO NOT REPORT

TEST NO. 3: ORIGINAL TIRES - NEW MOTOR

TEST NO. 5: DISTANCE ESTIMATED

SCT-1 (Cont'd)

TEST NUMBERS	9	10	11	12	13	14	15	16
TEST DATE	06/15/79	06/18/79	06/19/79	06/21/79	06/25/79	06/26/79	06/27/79	07/06/79
TEST TYPE	35MPH	B	55MPH	35MPH	FTP	D	55MPH	35MPH
BATTERY TYPE	PB-A	PB-A	NI-ZN	NI-ZN	PB-A	NI-ZN	NI-ZN	NI-ZN
BATTERY	EV-130	EV-130	ERC	ERC	EV-130	ERC	ERC	ERC
BATTERY ENERGY ECONOMY (MI/KWH)	5.35	2.86	3.81	5.58	2.68	2.92	3.74	5.24
RANGE (MILES)	80.4	47.4	48.4	121.3	10.9	26.6	37.2	94.4
BATTERY DISCHARGE ENERGY (KWH)	15.03	16.57	12.74	21.7	4.07	9.13	9.92	18.0
BATTERY REGEN. ENERGY (KWH)	0.01	0.43	0.01	0.01	0.15	0.33	0.02	0.01
BATTERY REGEN. ENERGY (%)	0.06	2.59	0.04	0.0	3.66	3.61	0.20	0.0
BATTERY DISCHARGE (AMP - HOURS)	147.4	N.A.	125.0	210.1	39.0	89.3	100.6	178.1
BATTERY REGEN. (AMP - HOURS)	0.0	0.3	0.0	0.0	0.6	0.0	0.0	0.0
BATTERY REGEN. AMPERAGE (%)	0.0	26.0	0.0	0.0	1.5	0.0	0.0	0.0
ARMATURE INPUT ENERGY (KWH)	14.01	14.06	12.49	20.09	3.73	8.64	9.74	16.78
ARMATURE REGEN. OUTPUT (KWH)	0.01	0.55	0.01	0.01	0.18	0.36	0.02	0.01
ARMATURE REGEN. OUTPUT (%)	0.1	3.9	0.1	0.0	4.8	4.2	0.2	0.0
FIELD ENERGY (KWH)	0.836	2.298	0.089	1.391	0.290	0.394	0.065	0.975
CONTROLLER EFFICIENCY (%)	98.7	96.7	98.5	98.8	98.7	98.9	98.8	98.6
ODOMETER READING (MILES)	2632.9	2713.2	2760.8	2810.1	2931.5	2942.5	2969.5	3024.7
BATTERY RECHARGE ENERGY EFFICIENCY(%)	68.60	69.31	N.A.	N.A.	54.33	N.A.	N.A.	N.A.
BATTERY RECHARGE AMPERAGE EFFICIENCY(%)	84.1	N.A.	N.A.	60.5	67.7	84.4	67.1	89.1
BATTERY TEMP. BEFORE (DEG F)	72.5	70.1	N.A.	N.A.	74.3	N.A.	74.3	74.5
BATTERY TEMP. AFTER (DEG F)	83.4	82.2	N.A.	N.A.	79.6	N.A.	90.4	91.6

* COMMENTS
TEST NO. 13: NOT A RANGE TEST - REGULAR, NOT EQUALIZATION RECHARGE

SCT-1 (Cont'd)

TEST NUMBERS	17	18	19	20	21	22	23	24
TEST DATE	07/10/79	07/11/79	07/12/79	07/23/79	07/25/79	07/28/79	07/31/79	08/01/79
TEST TYPE	35MPH	35MPH	35MPH	C	C	ACCEL	35MPH	C
BATTERY TYPE	PB-A	NI-ZN	PB-A	PB-A	PB-A	PB-A	PB-A	PB-A
BATTERY	EV-130	EHC	EV-130	EV-130	EV-130	EV-130	FACILITY	EV-130
BATTERY ENERGY ECONOMY (MI/KWH)	5.33	5.80	5.53	3.15	N.A.	N.A.	5.51	2.93
RANGE (MILES)	80.6	97.5	85.8	41.9	40.7	N.A.	46.2	38.6
BATTERY DISCHARGE ENERGY (KWH)	15.17	16.82	15.51	13.32	N.A.	N.A.	8.37	13.17
BATTERY REGEN. ENERGY (KWH)	0.003	0.01	0.03	0.67	0.00	0.00	0.01	0.34
BATTERY REGEN. ENERGY (%)	0.01	0.05	0.19	5.03	0.0	0.0	0.11	2.58
BATTERY DISCHARGE (AMP - HOURS)	150.0	166.6	153.0	135.3	136.0	N.A.	N.A.	132.1
BATTERY REGEN. (AMP - HOURS)	0.0	0.0	0.0	2.3	1.6	0.0	0.0	0.0
BATTERY REGEN. AMPERAGE (%)	0.0	0.0	0.0	1.6	1.2	0.0	0.0	0.0
ARMATURE INPUT ENERGY (KWH)	14.14	15.57	14.39	11.68	0.00	0.00	7.62	11.60
ARMATURE REGEN. OUTPUT (KWH)	0.003	0.01	0.03	0.85	0.00	0.00	0.01	0.45
ARMATURE REGEN. OUTPUT (%)	0.02	0.1	0.2	7.3	0.0	0.0	0.2	3.9
FIELD ENERGY (KWH)	0.786	1.052	0.894	1.4	N.A.	N.A.	0.528	1.315
CONTROLLER EFFICIENCY (%)	98.3	98.8	98.5	98.1	N.A.	N.A.	97.3	98.0
ODOMETER READING (MILES)	3119.4	3200.8	3296.2	3488.3	3534.0	N.A.	3680.8	3727.1
BATTERY RECHARGE ENERGY EFFICIENCY(%)	69.20	N.A.	71.94	N.A.	N.A.	N.A.	N.A.	70.61
BATTERY RECHARGE AMPERAGE EFFICIENCY(%)	82.7	55.4	85.4	80.9	84.7	N.A.	N.A.	84.6
BATTERY TEMP. BEFORE (DEG F)	76.7	75.1	80.5	74.	72.	N.A.	85.4	82.5
BATTERY TEMP. AFTER (DEG F)	87.8	92.0	89.8	100.	N.A.	N.A.	79.7	100.0

* COMMENTS

TEST NO. 17: DIAGNOSTIC TEST ONLY - DO NOT REPORT DATA

TEST NO. 19: DIAGNOSTIC TEST ONLY - DO NOT REPORT DATA

TEST NO. 20: ETS - NORTH BASE TEST - 9 MIN INTERRUPTION

TEST NO. 21: ETS-NORTH BASE TEST - ENERGY COUNTER PROBLEMS

TEST NO. 22: ETS- NORTH BASE TEST - NO DATA

TEST NO. 23: DIAGNOSTIC TEST ONLY - DO NO REPORT DATA

SCT-1 (Cont'd)

TEST NUMBERS	25	26	27	28	29	30	31	32
TEST DATE	08/03/79	08/07/79	08/10/79	08/14/79	08/16/79	08/21/79	08/28/79	08/29/79
TEST TYPE	C	35MPH	35MPH	D	ACCEL	55MPH	35MPH	55MPH
BATTERY TYPE	PB-A	PB-A	NI-ZN	NI-ZN	PB-A	NI-FE	NI-FE	NI-FE
BATTERY	EV-130	FACILITY	ENC	ENC	EV-130	WEST.	WEST.	WEST.
BATTERY ENERGY ECONOMY (MI/KWH)	2.89	5.64	6.33	2.94	4.66	4.27	6.12	4.38
RANGE (MILES)	36.7	63.6	99.0	15.6	49.3	72.9	121.1	75.8
BATTERY DISCHARGE ENERGY (KWH)	12.68	11.27	15.63	5.30	10.61	17.00	19.79	17.30
BATTERY REGEN. ENERGY (KWH)	0.31	0.01	0.01	0.18	0.19	0.01	0.01	0.01
BATTERY REGEN. ENERGY (%)	2.44	0.08	0.06	3.34	1.79	0.05	0.05	0.05
BATTERY DISCHARGE (AMP - HOURS)	127.7	N.A.	159.5	52.1	94.1	164.1	184.0	165.8
BATTERY REGEN. (AMP - HOURS)	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BATTERY REGEN. AMPERAGE (%)	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ARMATURE INPUT ENERGY (KWH)	11.18	10.28	14.24	5.09	9.86	16.70	17.37	16.92
ARMATURE REGEN. OUTPUT (KWH)	0.41	0.01	0.01	0.20	0.20	0.01	0.17	0.01
ARMATURE REGEN. OUTPUT (%)	3.7	0.1	0.1	4.0	2.1	0.0	1.0	0.1
FIELD ENERGY (KWH)	1.282	0.708	1.034	0.239	0.501	0.137	1.987	0.145
CONTROLLER EFFICIENCY (%)	98.2	97.5	97.7	99.0	98.4	98.5	97.8	98.6
ODOMETER READING (MILES)	3766.0	3803.5	3876.0	3974.6	3990.8	4080.3	4113.0	4233.8
BATTERY RECHARGE ENERGY EFFICIENCY(%)	69.29	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
BATTERY RECHARGE AMPERAGE EFFICIENCY(%)	83.4	N.A.	66.5	N.A.	N.A.	N.A.	N.A.	65.6
BATTERY TEMP. BEFORE (DEG F)	73.9	79.6	74.0	79.0	72.4	80.5	90.9	87.1
BATTERY TEMP. AFTER (DEG F)	92.5	127.9	122.0	94.3	84.3	142.9	111.0	115.2

* COMMENTS

TEST NO. 26: DIAGNOSTIC TEST ONLY, BATTERY TEMPS. MOVED TO DRIVE TRAIN

TEST NO. 28: BATTERY IS DEAD

TEST NO. 29: MISSED FIRST TWO ACCEL.

SCT-1 (Cont'd)

TEST NUMBERS	33	34	35	36	37	38	39	40
TEST DATE	08/30/79	09/05/79	09/06/79	09/07/79	09/12/79	09/25/79	09/26/79	09/27/79
TEST TYPE	D	B	D	35MPH	C	55MPH	35MPH	35MPH
BATTERY TYPE	NI-FE	NI-FE	NI-FE	NI-FE	PB-A	NI-ZN	PB-A	NI-ZN
BATTERY	WEST.	WEST.	WEST.	WEST.	EV2-13	YARDNEY	EV2-13	YARDNEY
BATTERY ENERGY ECONOMY (MI/KWH)	5.00	3.01	3.03	6.36	3.14	4.26	6.32	6.02
RANGE (MILES)	80.4	61.9	47.7	105.1	50.2	83.9	117.4	126.2
BATTERY DISCHARGE ENERGY (KWH)	16.09	20.55	15.78	16.51	15.90	19.69	18.58	20.96
BATTERY REGEN. ENERGY (KWH)	0.64	0.65	0.58	0.01	0.54	0.01	0.004	0.01
BATTERY REGEN. ENERGY (%)	3.97	3.16	3.67	0.06	3.37	0.05	0.02	0.04
BATTERY DISCHARGE (AMP - HOURS)	141.4	190.7	156.9	197.5	160.2	182.0	179.1	192.3
BATTERY REGEN. (AMP - HOURS)	0.0	0.0	3.4	0.0	1.0	0.0	0.0	0.0
BATTERY REGEN. AMPERAGE (%)	0.0	0.0	2.2	0.0	0.6	0.0	0.0	0.0
ARMATURE INPUT ENERGY (KWH)	15.12	16.68	14.84	14.70	14.25	19.20	16.88	18.46
ARMATURE REGEN. OUTPUT (KWH)	0.74	0.86	0.66	0.01	0.69	0.01	0.01	0.02
ARMATURE REGEN. OUTPUT (%)	4.9	5.2	4.4	0.0	4.8	0.0	0.0	0.1
FIELD ENERGY (KWH)	0.793	3.576	0.738	1.467	1.673	0.183	1.379	2.324
CONTROLLER EFFICIENCY (%)	98.6	98.5	98.7	97.9	99.6	98.4	98.2	98.9
ODOMETER READING (MILES)	4399.3	4358.2	4420.9	4468.9	4574.6	4626.3	4709.7	4826.5
BATTERY RECHARGE ENERGY EFFICIENCY(%)	N.A.	N.A.	N.A.	N.A.	75.65	N.A.	71.85	N.A.
BATTERY RECHARGE AMPERAGE EFFICIENCY(%)	N.A.	74.5	74.4	N.A.	84.7	92.7	84.1	N.A.
BATTERY TEMP. BEFORE (DEG F)	90.1	N.A.	N.A.	81.0	81.4	72.3	75.5	73.4
BATTERY TEMP. AFTER (DEG F)	124.4	N.A.	N.A.	123.7	93.1	101.5	82.3	74.4

* COMMENTS

TEST NO. 33: IDAC MAGNETIC TAPE 3 MIN. LATE IN STARTING

TEST NO. 34: BATTERY TEMPERATURES BAD - ELECTROLYTE SPILLAGE

TEST NO. 35: BATTERY TEMPERATURES BAD - ELECTROLYTE SPILLAGE

TEST NO. 36: BATTERY TEMPERATURES BAD - ELECTROLYTE SPILLAGE SEVERAL CELLS GETTING WEAK

TEST NO. 37: DIAGNOSTIC TEST ONLY

SCT- 1 (Cont'd)

TEST NUMBERS	41	42	43	44	45	46	47	48
TEST DATE	09/28/79	10/01/79	10/02/79	10/04/79	10/05/79	10/08/79	10/09/79	10/10/79
TEST TYPE	55MPH	C	55MPH	B	D	B	D	35MPH
BATTERY TYPE	PB-A	PB-A	PB-A	NI-ZN	PB-A	PB-A	NI-ZN	PB-A
BATTERY	EV2-13	EV2-13	EV2-13	YARDNEY	EV2-13	EV2-13	YARDNEY	EV2-13
BATTERY ENERGY ECONOMY (MI/KWH)	4.29	3.02	4.34	3.06	3.05	3.21	3.16	6.42
RANGE (MILES)	56.0	43.9	58.7	63.7	36.5	58.9	48.6	116.6
BATTERY DISCHARGE ENERGY (KWH)	13.56	14.53	13.51	20.82	11.96	18.33	15.36	18.17
BATTERY REGEN. ENERGY (KWH)	0.01	0.49	0.01	0.59	0.41	0.68	0.53	0.01
BATTERY REGEN. ENERGY (%)	0.07	3.37	0.07	2.83	3.42	3.70	3.45	0.05
BATTERY DISCHARGE (AMP - HOURS)	134.9	146.5	134.6	190.6	123.0	184.4	143.4	180.7
BATTERY REGEN. (AMP - HOURS)	0.0	1.1	0.1	0.1	2.6	0.6	3.0	0.0
BATTERY REGEN. AMPERAGE (%)	0.0	0.8	0.1	0.1	2.1	0.3	2.1	0.0
ARMATURE INPUT ENERGY (KWH)	13.29	13.00	13.29	16.66	11.39	15.37	14.52	16.75
ARMATURE REGEN. OUTPUT (KWH)	0.01	0.60	0.01	0.84	0.45	0.87	0.59	0.00
ARMATURE REGEN. OUTPUT (%)	0.1	4.6	0.1	5.0	3.9	5.7	4.1	0.0
FIELD ENERGY (KWH)	0.099	1.486	0.103	4.105	0.552	3.040	0.797	1.324
CONTROLLER EFFICIENCY (%)	98.78	99.7	99.1	99.7	99.8	99.9	99.7	99.4
ODOMETER READING (MILES)	4952.6	5010.3	5054.5	5112.9	5175.3	5211.7	5270.8	5319.3
BATTERY RECHARGE ENERGY EFFICIENCY(%)	65.93	67.29	68.56	N.A.	68.41	72.65	N.A.	73.78
BATTERY RECHARGE AMPERAGE EFFICIENCY(%)	80.2	82.3	82.4	92.9	83.9	85.8	92.0	85.1
BATTERY TEMP. BEFORE (DEG F)	75.9	69.6	74.6	72.1	73.2	68.5	N.A.	75.4
BATTERY TEMP. AFTER (DEG F)	89.2	84.4	88.4	90.8	91.7	77.4	N.A.	81.7

* COMMENTS
  TEST NO. 44: 15 MINUTE INTERRUPTION MOTOR IDLING DURING INTERRUPTION
  TEST NO. 45: DROVE EXTRA CYCLE PAST TERMINATION CRITERION ADJUST DATA ACCORDINGLY (DELETE 1 CYCLE)

SCT-1 (Cont'd)

TEST NUMBERS	49	50	51	52	53	62	63
TEST DATE	10/11/79	10/12/79	10/17/79	10/19/79	10/29/79	12/05/79	12/10/79
TEST TYPE	35MPH	D	B	C	35MPH	45MPH	C
BATTERY TYPE	NI-ZN	PB-A	PB-A	PB-A	NI-ZN	PB-A	PB-A
BATTERY	YARDNEY	EV2-13	EV2-13	EV2-13	YARDNEY	EV2-13	EV2-13
BATTERY ENERGY ECONOMY (MI/KWH)	6.02	3.07	3.11	3.02	6.14	5.30	2.89
RANGE (MILES)	116.4	35.5	58.3	43.9	127.7	80.3	35.8
ELAPSED TIME (MINUTES)	200.5	73.7	335.0	165.0	219.8	107.9	137.0
BATTERY DISCHARGE ENERGY (KWH)	19.32	11.55	18.73	14.55	20.81	15.14	12.38
BATTERY REGEN. ENERGY (KWH)	0.01	0.41	0.66	0.43	0.01	0.01	0.45
BATTERY REGEN. ENERGY (%)	0.05	3.54	3.52	2.95	0.04	0.06	3.63
BATTERY DISCHARGE (AMP - HOURS)	178.2	117.3	189.4	144.6	190.9	150.3	126.9
BATTERY REGEN. (AMP - HOURS)	0.0	0.0	0.7	0.6	0.0	0.2	3.9
BATTERY REGEN. AMPERAGE (%)	0.0	0.0	0.4	0.4	0.0	0.1	3.1
ARMATURE INPUT ENERGY (KWH)	17.16	11.02	15.70	13.05	18.62	14.72	11.18
ARMATURE REGEN. OUTPUT (KWH)	0.01	0.45	0.83	0.55	0.10	0.01	0.53
ARMATURE REGEN. OUTPUT (%)	0.0	4.0	5.3	4.2	0.5	0.0	4.8
FIELD ENERGY (KWH)	1.964	0.513	2.959	1.492	2.176	0.258	1.226
CONTROLLER EFFICIENCY (%)	98.9	99.8	99.6	99.9	99.9	98.9	99.9
ODOMETER READING (MILES)	5435.6	5552.0	5590.5	5649.0	5693.5	6187.6	6267.6
BATTERY RECHARGE ENERGY EFFICIENCY(%)	N.A.	65.93	74.95	71.15	N.A.	67.44	N.A.
BATTERY RECHARGE AMPERAGE EFFICIENCY(%)	N.A.	82.1	89.3	83.4	N.A.	81.9	N.A.
BATTERY TEMP. BEFORE (DEG F)	N.A.	71.5	68.5	73.4	69.6	71.4	N.A.
BATTERY TEMP. AFTER (DEG F)	N.A.	91.4	79.0	88.2	91.2	91.5	N.A.

* COMMENTS

TEST NO. 62: BATTERIES DYING

TEST NO. 63: BATTERIES DYING 1 CYCLE INTERRUPTED BY ABOUT 1 MIN. DELAY

APPENDIX D

ERRATA

SCT R-1 ELECTRIC ROAD-LOAD ERROR

After the tests described in this report and the report itself were completed, a problem was discovered with the coast-down tests for the South Coast Technology R-1 Electric. By the time the problem was noted, the performance tests had been completed. In addition, the vehicle had suffered damage to the motor and transmission which made it impossible to repeat the coast downs. The net result is that the performance results, range, and energy economy reported here are optimistic for this particular vehicle. Note, however, that the objective of the tests (see Section III) was to provide a base from which comparative tests of batteries (with the same vehicle) could be made. Since the error from the coast-down tests affected all dynamometer range tests made with the SCT vehicle, the data are acceptable for comparative purposes.

The problem arose because the 1219 m (4000 ft) portion of the runway used for the coast downs (see Reference 4 for additional information) was assumed to have a constant grade of 0.18%. The data from a detailed survey showed that the 1219 m (4000 ft) section in reality consists of two sections of about equal length with grades of 0.13% and 0.23%. The problem was further complicated because no attempt was made to record where on the runway the coast down occurred. This latter step was not needed if indeed the grade had been constant over the entire 1219 m (4000 ft) length. Therefore the data cannot be corrected with any confidence.

However, after the tests reported here, a second SCT R-1 Electric was subjected to proper coast down and dynamometer tests. While these tests do not lend themselves to a simple adjustment of the results of this report, they have been used to make an estimate of the errors in range resulting from the improper coast downs. These estimates are based on both the coast down and dynamometer data for the second vehicle and represent the largest error that could be estimated from the two sources.

Although exact positions on the runway are unknown, both the 90 km/h (50 mi/h) and 24 km/h (15 mi/h) tests were, in general, conducted at the extreme ends of the runway and therefore are most likely to have the largest error. The direction of the errors was such as to understate the road load. The 56 km/h (35 mi/h) data was, in general, obtained near the middle of the runway and, in the case of the opposite direction tests, are more likely to cancel the effects of slope as they were intended to do. The maximum error which could have resulted is approximately 32 N (7.2 lb_f). The total road load at 56 and 24 km/h (50 and 15 mi/h) was 427 and 191 N (96.1 and 43.0 lb_f), respectively.

Reference 4 shows that the loads actually set into the dynamometer differed from the runway values. The dynamometer load at 24 km/h (15 mi/h) could not be set low enough even though the lift technique was used (hindsight has shown that the runway value was too low). As a compromise, the (50 mi/h) dynamometer load was set lower than the runway load and the (15 mi/h) load was then higher than the runway value. Therefore, the percentage error for the low speed tests is less than for the higher speeds. It is estimated that the range values given in for the SCT R-1 Electric are too large by the following amounts:

56 km/h (35 mi/h) - 4%
88 km/h (55 mi/h) - 11%
Schedule C cycle - 0%
Schedule D cycle - 11%

Note also that when the second SCT vehicle was tested at a correct dynamometer setting, it was unable to complete a 88 km/h (55 mi/h) or a D cycle because the motor temperature exceeded the safe limit and the vehicle automatically went into a current limit mode. Therefore, applying the corrections given above will adjust for the errors in road load, but will not predict inherent vehicle limitations which only become apparent with the proper road load. Also note that the road-load errors were approximately one-half the values stated for range.

The other three vehicles discussed in this report were not affected by the slope problems just discussed. Each of these vehicles were fortuitously tested only on the flat 610 m (2000 ft) portion of the runway. Although the slope problem had not been identified at the time the latter three vehicles were tested for road-load determinations, refinements to the coast-down procedure started each test at the far end of the runway. In addition, the higher road-load characteristics of these three cars resulted in much shorter coast distances. Therefore, the shorter constant slope segment was sufficient to complete any specific segment (high or low speed) of the coast-down process without a change of slope occurring.