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Electric & Hybrid Vehicle System
Research & Development Project

DOE/CS-54209-6
Distribution Category UC-96

Vehicle Test Report: Battronic Pickup Truck

Theodore W. Price
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January 1, 1982

Prepared for
U.S. Department of Energy
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ABSTRACT

The Battronic Pickup Truck, an electric vehicle designed and constructed by the Battronic Truck Corporation (a subsidiary of Boyertown Auto Body Works of Boyertown, Pennsylvania) was tested at the Jet Propulsion Laboratory's (JPL) dynamometer facility in Pasadena, and at JPL's Edwards Test Station, located near Lancaster, California. The tests were conducted between 29 February and 24 March 1980. These tests were performed to characterize certain parameters of the truck and to provide baseline data that can be used for the comparison of improved batteries that may be incorporated into the vehicle at a later time.

The vehicle tests were concentrated on the electrical drive subsystem; i.e., the batteries, controller, and motor. The tests included coastdowns to characterize the road load and range evaluations for both cyclic and constant speed conditions. A qualitative evaluation of the vehicle's performance was made by comparing its constant speed range performance with those vehicles described in the document titled "State of the Art Assessment of Electric and Hybrid Vehicles." The Battronic Truck was approximately equal to the majority of the vehicles tested in that 1977 Assessment.

GLOSSARY

ABBREVIATIONS AND ACRONYMS

DOE	U.S. Department of Energy
EHV	Electric and Hybrid Vehicle
ESB	Electric Storage Battery Company
ETS	Edwards Test Station
IDAC	Integrated Data Acquisition and Control
JPL	Jet Propulsion Laboratory
MERADCOM	Mobility Equipment Research and Development Command
PWM	pulse width modulation
SAE	Society of Automotive Engineers
SCR	silicon-controlled rectifier

ACKNOWLEDGMENT

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SECTION I

SUMMARY

The Battronic Pickup Truck (Batt Truck) was tested at the Jet Propulsion Laboratory's (JPL) dynamometer facility in Pasadena, and at JPL's Edwards Test Station (ETS), Edwards Air Force Base. The tests were conducted between February and September 1980, and were performed to characterize the Battronic truck in preparation for use in comparing near-term batteries.

The Battronic vehicle involved a ground-up design based on the Battronic minivan. The vehicle has a rear-wheel drive and is propelled by a General Electric dc motor. This motor has a series-wound field and is rated at a peak power of 23.9 kW (32 hp); it is controlled by pulse-width modulation of the armature current. The vehicle is powered by twenty-four 6-V ESB Exide Ev-106 lead-acid batteries connected in series. The traction motor drives the vehicle through a two-speed clutchless transmission and 3.73 rear axle. Regenerative braking has been incorporated into the design of the vehicle in addition to the conventional four-wheel hydraulic brake system.

All tests were conducted using a vehicle test weight of 2608 kg (5750 lb). The test program included coastdown tests (to characterize road load power) at ETS as well as constant speed and cyclic range tests at the Pasadena site. The test results, summarized in Table 1-1, are the subject of this report.

U.S. Customary units were used in the collection and reduction of data. The units were converted to the International System of Units for presentation in this report. U.S. Customary units are included in parentheses.

Table 1-1. Summary of Range Tests -- Battronic Truck

Test No	Speed, km/h	(mph)	Range, km	(mi)	Battery Energy Consumption, MJ/km	(Wh/mi)
3	40.2	25	77.52	48.17	0.826	369.4
8	40.2	25	77.66	48.26	0.824	368.3
4	72.4	45	39.20	24.36	1.128	504.3
7	72.4	45	39.04	24.36	1.134	507.2
2	"B"	CYCLE	41.44	25.75	1.286	575.2
5	"B"	CYCLE	46.22	28.72	1.307	584.4
9	"B"	CYCLE	46.97	29.19	1.286	575.0
1	"C"	CYCLE	24.46	15.20	1.393	622.8
6	"C"	CYCLE	30.85	19.17	1.389	621.3
10	"C"	CYCLE	28.05	17.43	1.376	615.1

SECTION II

INTRODUCTION

The vehicle tests and the data presented in this report are in support of Public Law 94-413 enacted by congress on September 17, 1976. A section of this law requires the U.S. Department of Energy (DOE) to promote increased research and development of electric and hybrid vehicles. In consonance with this act of congress, DOE awarded contracts for two each of four different vehicles to small business concerns in June 1978. This has become known as the "2 x 4" program. Four of these vehicles, including the Battronic Pickup Truck, were delivered to JPL for use in the assessment of near-term[1] batteries.

The vehicle tests and data included in this report are part of JPL's Vehicle Test and Evaluation Task and support the Electric and Hybrid Vehicle (EHV) System Research and Development Project objectives. Both road and dynamometer tests were conducted using JPL procedures based on the Society of Automotive Engineers "Electric Vehicle Test Procedure," SAE J227a (Reference 2-1). Results include vehicle driving range at steady speeds and driving schedules.

The primary purpose of the near-term battery assessment task is to determine "in vehicle" performance of various near-term batteries (i.e., nickel-iron, nickel-zinc). Because the focus of the tests was on batteries, the test activities were structured so that only certain vehicle parameters were characterized. The emphasis was on the battery performance as measured by vehicle range, the energy consumed per mile driven, and the energy gained from regeneration. The bulk of the vehicle test effort was devoted to the vehicle-to-battery interface and to the battery performance itself. Other vehicle parameters such as steering, braking, and passenger accommodations, were not characterized.

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[1]For the purposes of this report, near-term means batteries which could be available in commercial quantities in the next ~5 years, and which also have the potential for greater capacity than batteries currently available.

SECTION III

TEST OBJECTIVE AND SCOPE

The work described in this report is a subset of a larger effort. The primary purpose of this larger effort was to evaluate several types of near-term batteries in actual vehicle use. The method selected for the evaluation was to compare the performance of several vehicles equipped with lead-acid batteries (of the vehicle manufacturer's choice) with the performance of the same vehicle when equipped with a set of near-term batteries. One obvious requirement for this comparison method was to maintain the test conditions and vehicle state constant over the course of all tests of any single vehicle.

With the above background in mind, the objective for the baseline tests described in this report was to obtain a set of reference data using lead-acid batteries which could be used as a basis for comparison with other battery types.

To aid in accomplishing this objective, a set of test requirements was formulated. The emphasis of the test requirements was directed at the performance of the batteries under a variety of operating conditions. A necessary adjunct to determining the battery performance was a need to monitor the vehicle "state of tune" over the course of the test program. The performance of the vehicle itself was also of interest, but secondary to the battery needs. Nearly all the measurements were directly related to the propulsion subsystem.

The test requirements were specific in defining the configurations and conditions of the tests. This was necessary so that test repeatability could be accomplished. All the performance tests were conducted on a chassis dynamometer, again, for the purpose of achieving repeatability and stability. The only tests performed in the field were those necessary to establish the "road load" and hence the dynamometer settings.

SECTION IV

VEHICLE DESCRIPTION AND OPERATION

A. SYSTEM AND COMPONENT DESIGN

The Battronic Pickup Truck was designed and constructed by the Battronic Truck Corporation (a subsidiary of Boyertown Auto Body Works) of Boyertown, Pennsylvania, and incorporates the basic frame of the Battronic minivan. The pickup, however, was constructed from lighter weight materials (as compared with the minivan) and incorporates improved components. Some of these components are: (1) a new collapsible steering column; (2) lighter weight, higher energy density batteries; (3) a motor controller modified to incorporate regenerative braking; and (4) lower rolling resistance tires. The external appearance of the pickup is shown in Figures 4-1 and 4-2. Figure 4-3 depicts the internal orientation and location of major components within the vehicle. The functional integration of these components is shown in the block diagram of Figure 4-4. A compilation of the vehicle's specifications and ratings is shown in Table 4-1.

The curb weight of the vehicle, as built by Battronic, is 2268 kg (5000 lb) with a manufacturer's gross vehicle weight (GVW) of 2631 kg (5800 lb). Load capacity of the truck is 227 kg (500 lb) in addition to the driver and one passenger 136 kg (300 lb). The vehicle test weight was 2608 kg (5750 lb). This was the dynamometer inertia weight closest to the GVW of 2631 kg (5800 lb). The next increment of weight would have placed the vehicle test weight at 2665 kg (5875 lb).

The vehicle is equipped with P225-75-R15-size steel-belted Firestone 721 radial tires inflated to a pressure of 241 kPa (35 psig) cold. The vehicle is 4.15 m (163.2 in.) long, 1.92 m (75.75 in.) wide, 1.93 m (76 in.) high, and has a wheelbase of 2.49 m (98 in.). The cargo bed is 1.93 m (76 in.) long, 1.85 m (73 in.) wide, 0.66 m (26 in.) high, and has a volume of 1.61 m^3 (57 ft^3). The vehicle body is a two-door model with a hinged tailgate for the cargo bed, and two sliding windows on each door. In addition, a ventilator is located in front of each door (operated from the driver's compartment) to provide passenger ventilation in place of air conditioning. A 20,000-Btu gasoline burning hot air heater, with a 3-gal fuel tank located under the cargo bed, allows for windshield defrosting in cold weather. Two bucket seats provide seating for the driver and one passenger.

Vehicle suspension consists of laminated leaf-type springs dampened by direct-acting hydraulic shock absorbers located at each wheel. The steering gear assembly is a worm and nut type. The four-wheel hydraulic brake system incorporates self-adjusting brakes and separate front and rear hydraulic systems with independent operations. A warning light is located on the instrument cluster to warn the driver when a significant pressure differential exists between the front and rear brake systems.

Batteries are carried in two compartments, one on each side of the vehicle, under locked doors which are hinged for battery access. Each of the side compartments contains two roll-out battery racks, and each rack houses six battery modules for a total of 24 batteries (Figure 4-5).

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Figure 4-1. Front-Side View of Battronic Pickup Truck

Figure 4-2. Rear-Side View of Battronic Pickup Truck

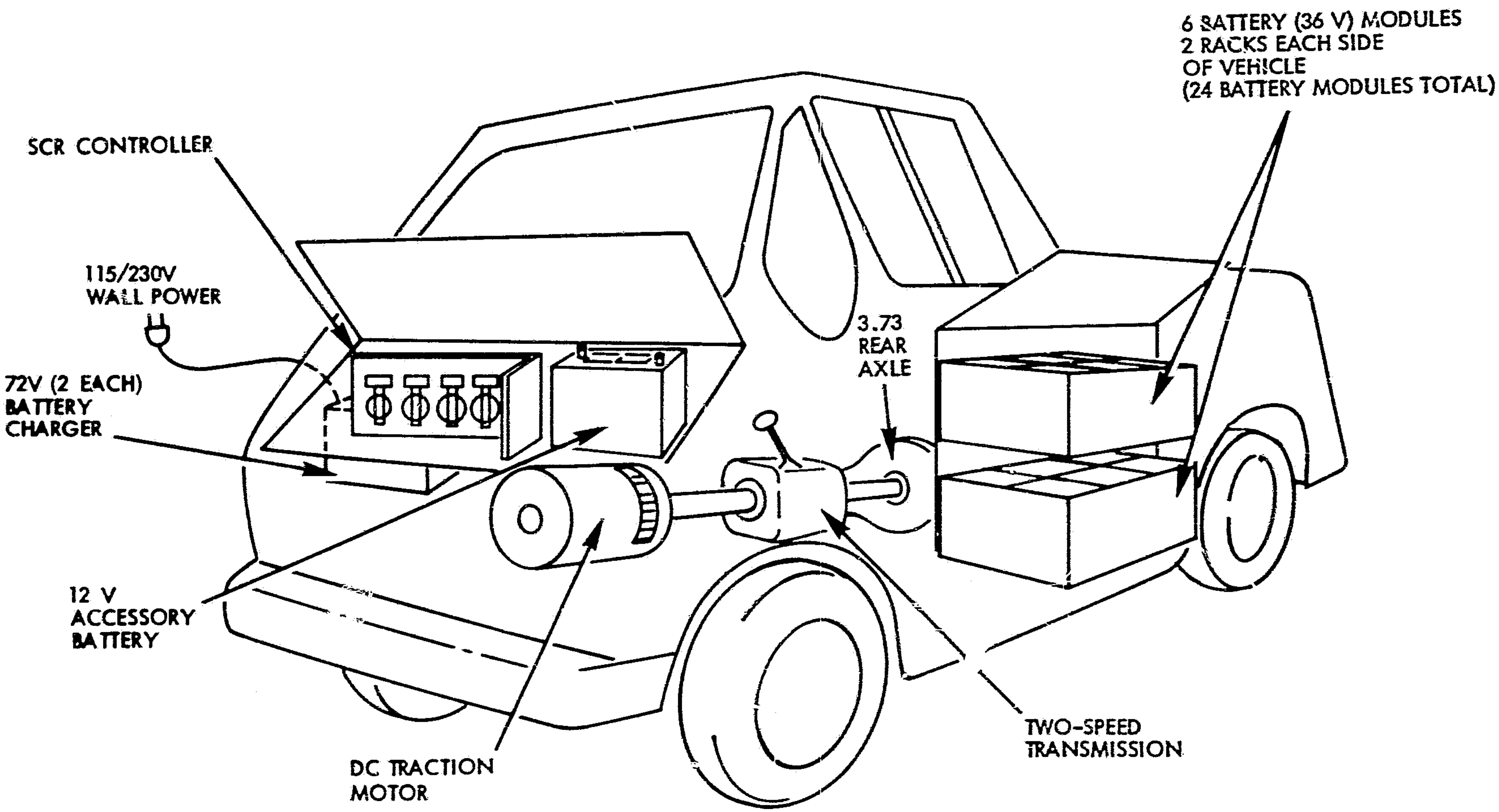

Figure 4-3. Cross-Sectional View of Battronic Truck Showing Major Component Placement (Scale Not Exact)

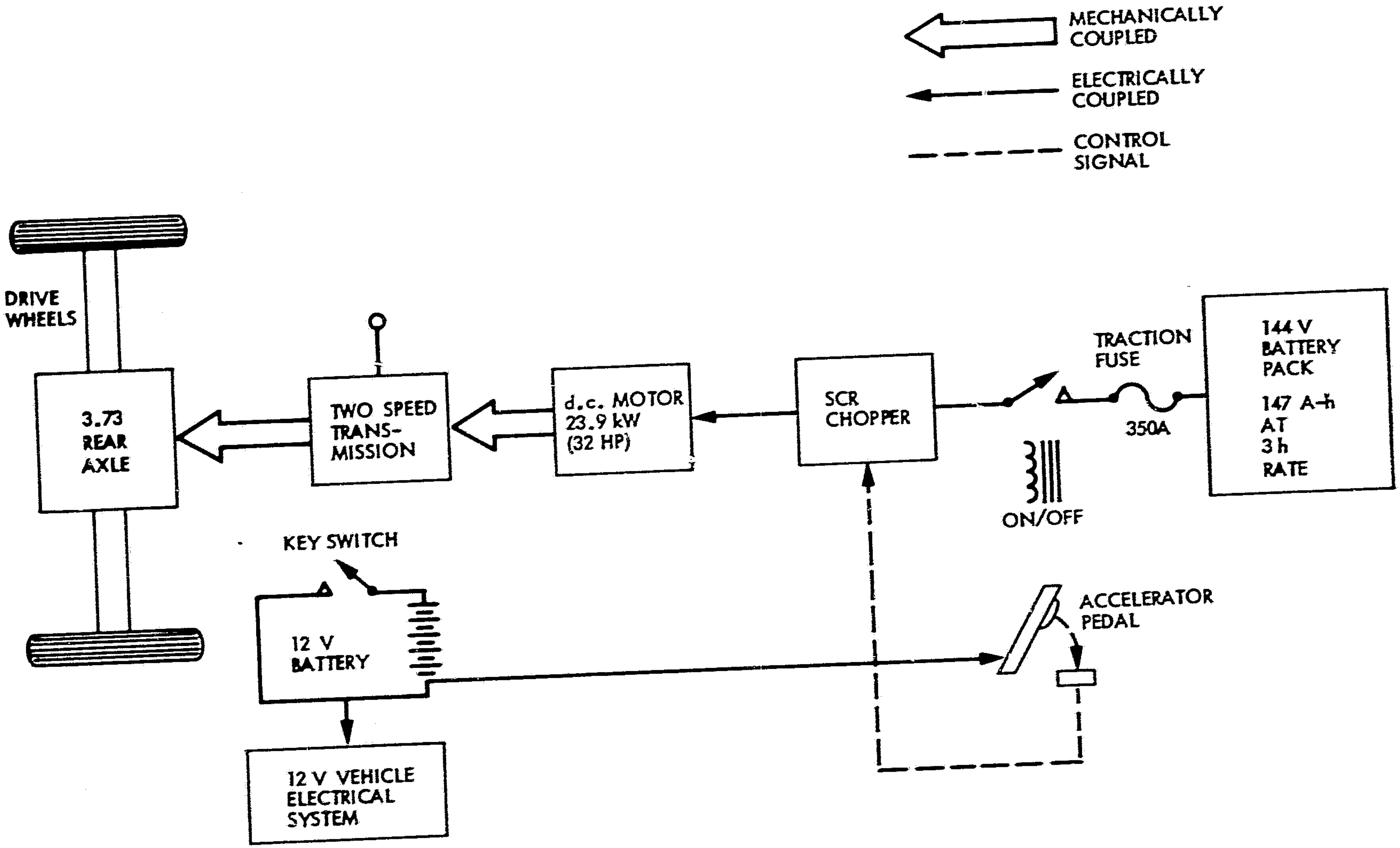

Figure 4-4. Battronic Truck Propulsion System Block Diagram

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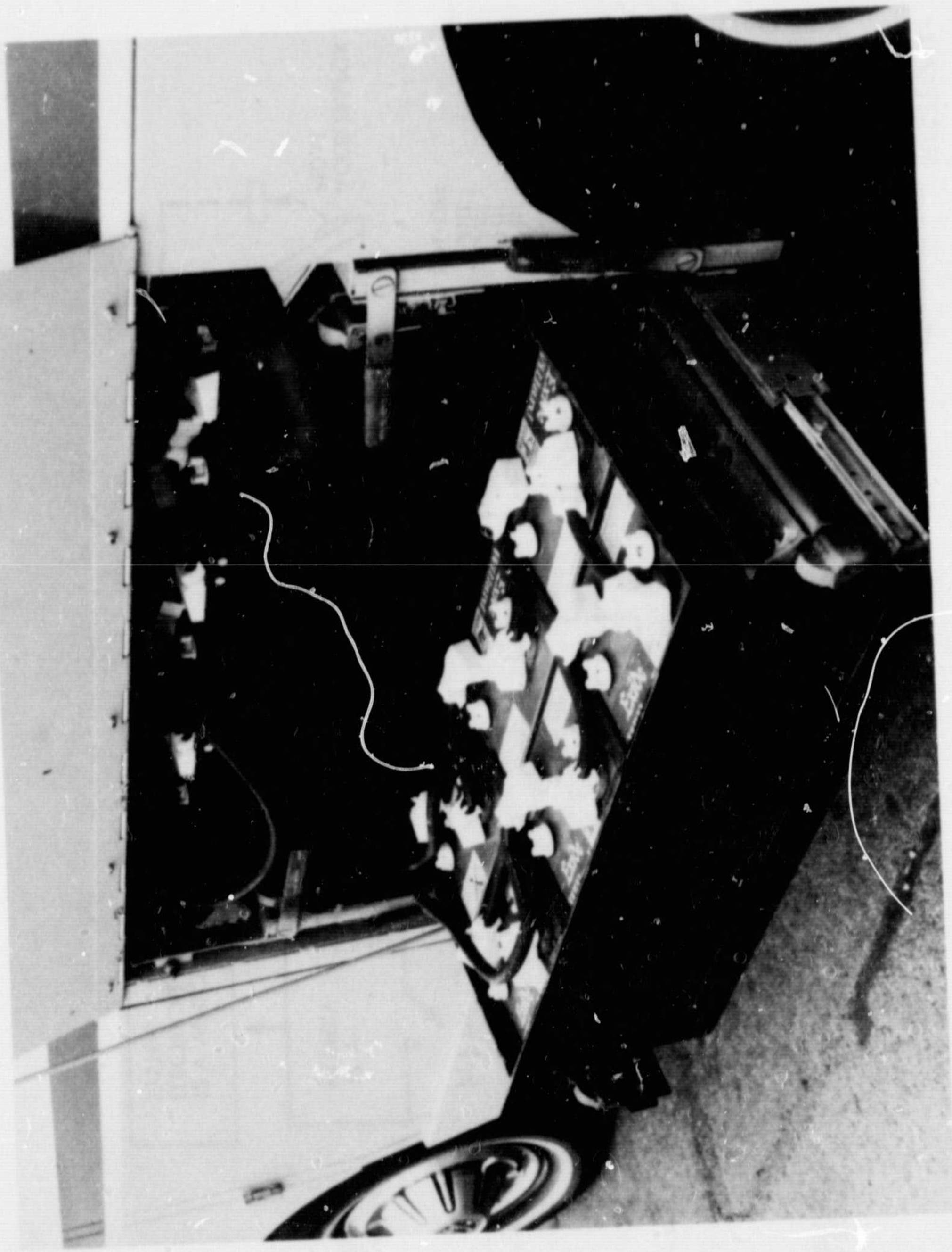

Figure 4-5. Right Side Roll-Out Battery Pack (Left Side Pack Not Shown)

Table 4-1. Specification Summary

Vehicle Origin	
Developer	Battronic Truck Corporation for DOE
Propulsion System/ Electrical Components	General Electric Company and Cableform
Propulsion Batteries	ESB Exide
Vehicle Design	Boyertown Auto Body Works
Electric Drive Subsystem	
Propulsion Motor	
Type	dc Traction, Series-wound
Model	5BT 2366C10
Manufacturer	General Electric Company
Voltage Rating	144 V
Peak Power	23.9 kW (32 hp)
Controller	
Type	SCR Armature Chopper
Model	Pulsomatic Mark 10
Manufacturer	Cableform
Current Limit	450 A
Vehicle Weight	
Gross Weight	2630.8 kg (5800 lb)
Curb Weight	2267.9 kg (5000 lb)
Driver Weight	68.0 kg (150 lb)
Passenger Weight	68.0 kg (150 lb)
Payload Weight	226.7 kg (500 lb)
Test Weight (Dyno)	2608.1 kg (5750 lb)
Dimensions	
Wheelbase	632 m (98 in.)
Length	1053.63 m (163 5/16 in.)
Width	488.71 m (75 3/4 in.)
Height	490 m (76 in.)
Cargo Volume	1.61 m^3 (57 ft^3)

Table 4-1. Specification Summary (Cont'd)

Tires		
Type	Steel-belted radial	
Model	721	
Size	P225/75R15	
Manufacturer	Firestone	
Pressure (psig)	241 Pa	(35 psig)
Rolling Radius	80.83 m	(12.53 in.)
Suspension		
Springs	Laminated leaf	
Shock Absorbers	Direct acting, Hydraulic	
Steering System	Worm and Nut	
Brakes		
Type	Hydraulic, dual acting, independent front and rear	
Drum Diameter (front and rear)	70.99 m	(11.005 in.)
Regenerative Braking	Yes	
Battery Chargers		
Number	Two	
Type	Ferro Resonant	
Model	9455	
Manufacturer	Lester	
Location	On-board	
Charging Source	115 V/250 V/25 A	
Output	12 - 72 Vdc	
Battery Subsystem		
Propulsion Batteries		
Type	Lead-acid, EV-106	
Number	24	
Manufacturer	ESB Exide	
Voltage	144 V	
Ampere-Hour Capacity	147 @ c/3 rate	
Battery Weight	685.8 kg (1512 lb)	

Table 4-1. Specification Summary (Cont'd)

Accessory Battery	
Type	Lead-acid, Series 6000 MF
Model	520 Titan
Manufacturer	General Battery Corporation
Voltage	12-V
Vehicle Subsystem	
Type	Pickup
Number of Doors (Type)	Two (hinged)
Number of Windows (Type)	Two (fixed) and Two (sliding)
Number of Seats (Type)	Two (bucket)
Transmission	Two-speed manual gearbox (1:1 and 1:1.36) gear ratios
Differential	Hypoid 3.73 gear ratio
Rear Axle	Semi-floating

The batteries are secured in position by bars bolted to the respective rack. Two levers, one on each side of the rack at the bottom, are lowered to prevent rack movement during vehicle operation. The levers can be raised and each six-module rack rolled out to mechanical stops for battery access and maintenance. There is an electrical quick-disconnect at each of the four roll-out modules. These allow the series string to be broken and thus provide a safety feature.

Propulsion power is derived from twenty-four, 6-V lead-acid battery modules manufactured by the Electric Storage Battery Company (ESB), Exide model no. EV-106. These batteries are rated at approximately 147 A-h for a 3-h discharge time (49 A for 3 h). The total battery weight is 686 kg (1512 lb). The battery weight fraction of the pickup as delivered to JPL was 30%. Figure 4-6 is a schematic of the electric power distribution system and shows the necessary switching and controls provided for vehicle operation.

The vehicle is propelled by a series-wound dc traction motor manufactured by the General Electric Company (model 5BT2366 C10). The peak rated power of the motor is 23.9 kW (32 hp). An upper limit to the motor current of approximately 450 A is provided by the controller. Additional motor protection is provided by a time-delay fuse rated at 350 A, located in the electrical system between the main battery pack and the controller. An external blower supplies cooling air through flexible tubing to the motor.

A silicon-controlled rectifier (SCR) chopper, manufactured by Cableform, provides speed control to the traction motor. All power to the series-connected field and armature passes through the SCR controller. The SCR is used as a

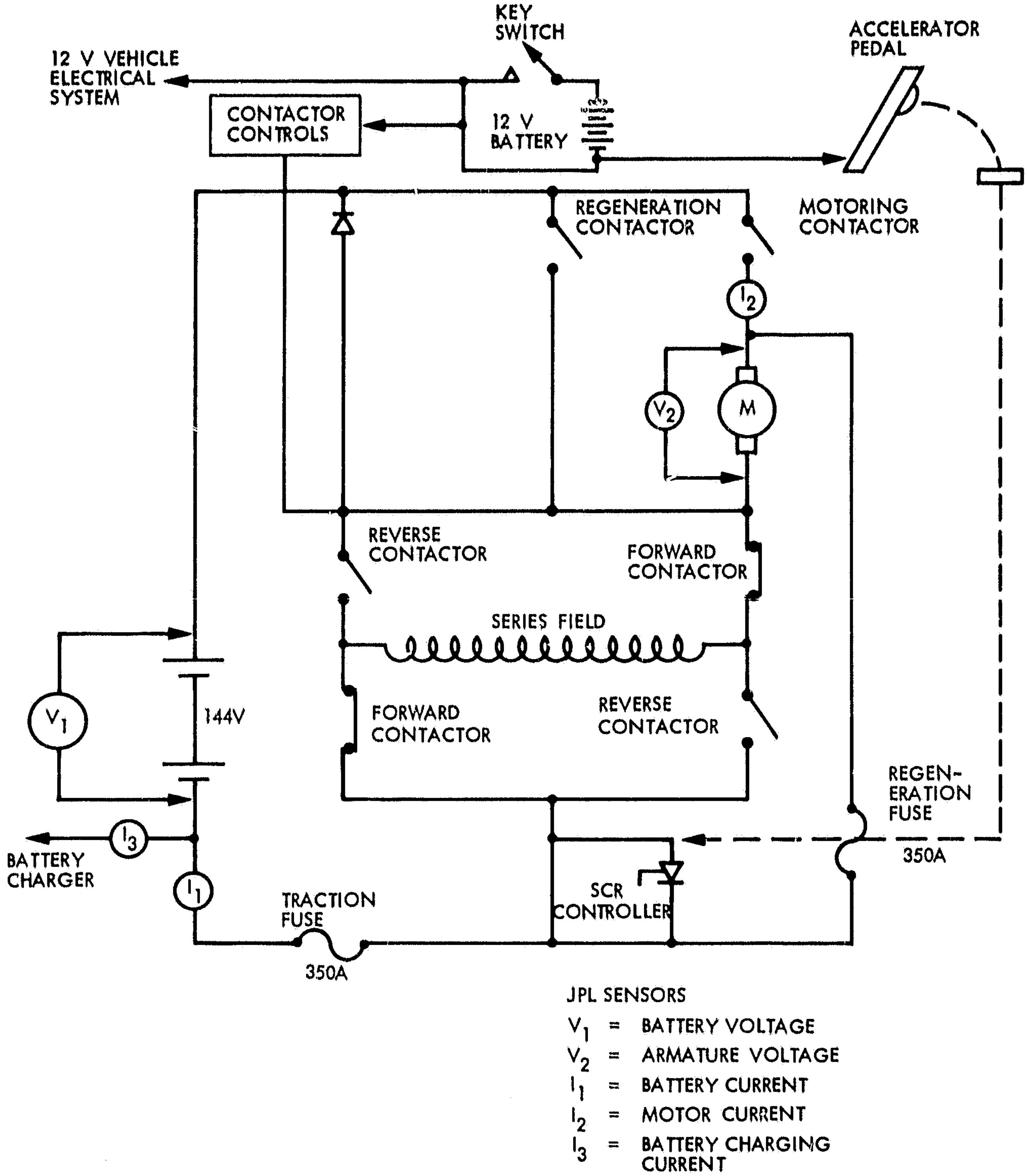

Figure 4-6. Battronic Truck Electric Power System -- Simplified Schematic

latching switch, and it may assume either a conducting or non-conducting state (on or off). The on (conducting) time is continually modified by accelerator position and motor speed. This switching process is commonly referred to as "pulse width modulation" (PWM). Armature current assumes whatever value (up to a 450 A controller limit) is required until the vehicle attains the speed commanded by the controller. The regenerative braking is activated by a light pressure on the brake pedal. There is no regenerative braking until the initial pedal pressure is applied (see page 7-4).

The traction motor drives the vehicle through a two-speed transmission manufactured by the New Process Corporation. The gear ratios are: low 1.36:1 and high 1:1. However, the manual transmission does not employ a clutch so the gear selection must be accomplished while the vehicle is stationary. The transmission cannot be shifted once the vehicle is in motion without risking transmission damage. The manufacturer recommends a maximum speed of 72 km/h (45 mph) with the transmission in low range.

During low-speed coastdown tests the vehicle batteries were utilized to accelerate the vehicle before the coast. When the desired speed was reached, the gearshift control lever was moved to the neutral position to disengage the drivetrain and reduce vehicle frictional losses. The coastdowns were somewhat complicated by the lack of a detent, or stop, in the transmission to identify the neutral position. The driver must assume it is approximately half-way between the low-speed gear position and the high-speed gear position. However, lack of the (neutral gear position) should present no particular problem during normal operation.

Vehicle power is delivered to the rear wheels through a semifloating rear axle using hypoid gears. The differential ratio is 3.73:1. A 12-V auxiliary battery provides power for the electronic controller and contactor controls, the accelerator start switch, emergency shut-off button, lights, windshield wipers, and traction motor cooling fan. During charging of the main traction battery, the auxiliary battery receives its charge from one of the onboard chargers. During vehicle operation, the accessory battery is recharged by a 12-V alternator which is belt-driven from the traction motor.

Dashboard instruments include: battery state-of-charge meter, propulsion battery pack voltage meter, armature current meter, auxiliary battery amp meter, motor high temperature indicator light, odometer, and speedometer. Additional features include a forward, reverse, and neutral toggle switch (motor polarity is reversed to drive the vehicle in reverse) with position indicator lights at each location, and a quick-disconnect shut-off button that allows a rapid and positive break of the battery pack power in an emergency. The instruments and controls as installed in the vehicle are listed in Table 4-2, and a schematic of their location is shown in Figure 4-7.

B. BATTRONIC PICKUP OPERATION

The vehicle may be placed in motion by completing the following operations:

(1) Place the ignition key in the switch and turn to the "on" position.

Table 4-2. Battronic Instruments and Controls

1. Speedometer and odometer indicators
2. Right turn indicator lamp (green lens)
3. Left turn indicator lamp (green lens)
4. State-of-charge meter
5. Ammeter - 12-V accessory battery
6. Hand brake indication light (red lens)
7. Motor Hi-Temperature indication light (red lens)
8. Brake System failure warning lamp (red lens)
9. Head Lamp hi-beam indicator lamp (blue lens)
10. Vehicle exterior lamp switch knob
11. Lamp switch identification lamp (white lens)
12. Dome lamp toggle switch
13. Dome switch identification lamp (white lens)
14. Windshield wiper control knob
15. Windshield wiper control lamp (white lens)
16. Emergency shut-off (panic) button (red)
17. Defroster control knobs
18. Defroster control identification lamp (white lens)
19. Heater control switch
20. Heater control identification lamp (white lens)
21. Heater temperature control knob
22. Temperature control identification
23. Directional control toggle switch (three-position)
24. Reverse indicator light
25. Forward indicator light
26. Neutral indicator light
27. Voltmeter - motor voltage
28. Ammeter - armature current

Note: (Schematic of Location in Figure 4-7)

(2) Place the directional control toggle switch in the forward or reverse position.

(3) Release the manual brake control lever completely.

(4) Gradually depress the accelerator pedal until the vehicle moves.

To obtain the optimum vehicle performance and most efficient operation, the readings of the armature current meter and motor voltage meter are an aid. The vehicle should be operated so that the motor voltage is kept as high and the armature current as low as possible.

Applying slight pressure to the brake pedal, while decelerating, energized the regenerative braking system. Further pressure on the pedal activated the four-wheel hydraulic service brakes.

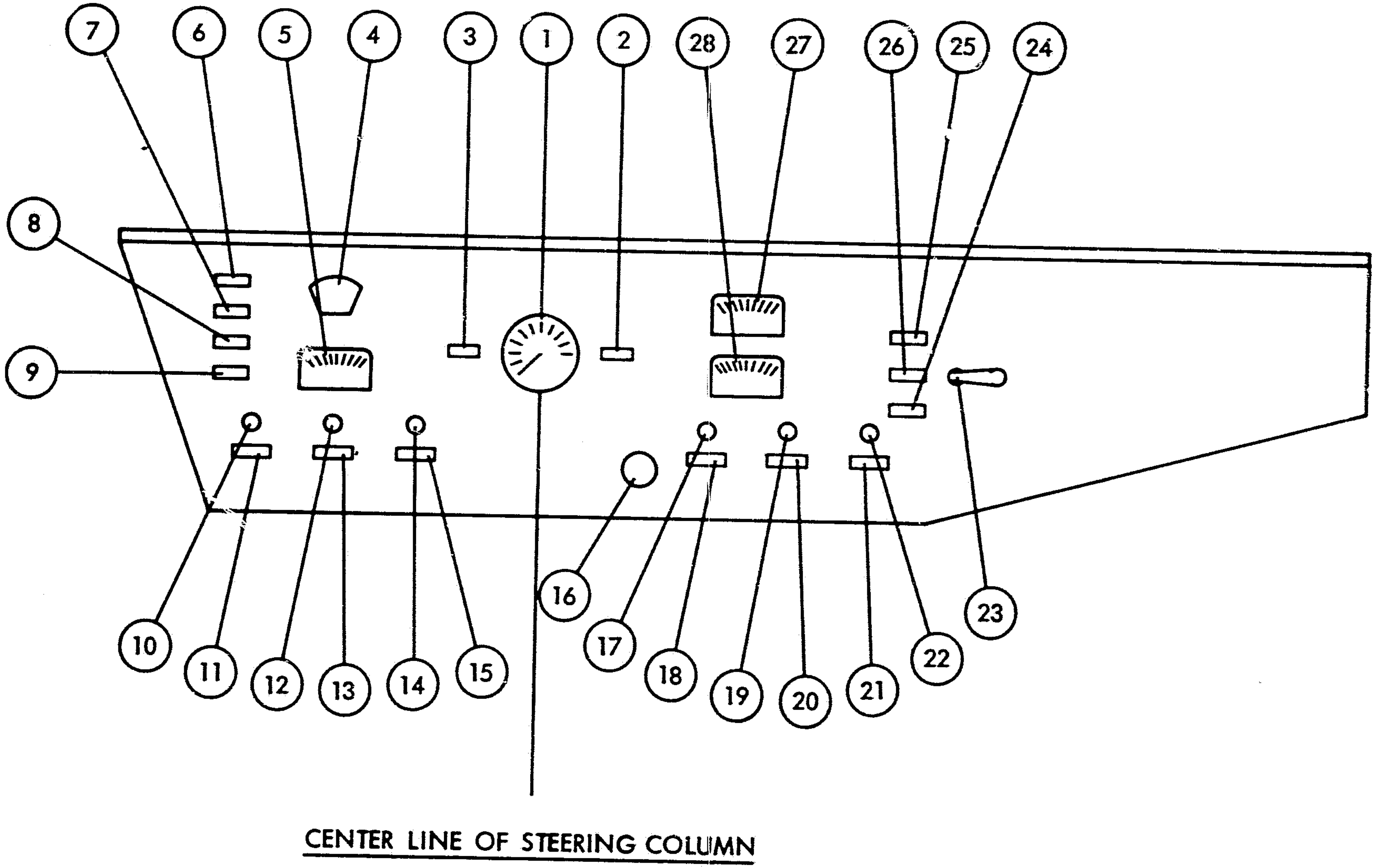

Figure 4-7. Battronic Instrument Panel

C. BATTERY CHARGERS

The vehicle is equipped with two onboard 60-cycle, single-phase (model 9455) 72 Vdc battery chargers, manufactured by the Lester Electrical Company. Each charger is connected to a 115-V or 230-V electrical outlet, and supplies direct current to twelve of the twenty-four propulsion battery modules. In addition, one of the chargers supplies charging power to the 12-V auxiliary battery. The chargers are equipped with a summer-winter switch. Following a battery charge, and if the external power source remains connected, the charger will automatically turn back on, periodically, to keep the batteries fully charged. With the switch in the summer position (ambient temperature above 10°C (50°F)), the chargers turn on approximately every 2 1/2 days until the voltage increase rate becomes less than 24 mV/h. Winter position of the switch (ambient temperature below 10°C (50°F)) allows the chargers to turn on approximately every 3 to 4 hours. This feature will tend to keep the batteries slightly warmer, therefore increasing their output capacity over what could be realized if the batteries were allowed to cool.

An onboard blower, with a separate 115-V power cord, supplies cooling and ventilation air over the twenty-four battery modules during battery charging. Each charger is limited to a maximum current of 25 A. As the battery voltage increases during battery charge, the current gradually decreases. Charge is automatically terminated when the voltage increase rate becomes less than 24 mV/h.

After completion of coastdown testing at ETS, and prior to initiation of baseline testing on the dynamometer at JPL in Pasadena, one of the chargers malfunctioned during a normal, routine charging operation. The unit was removed from the vehicle and returned to the Lester Company for repair or replacement. As a result, all baseline testing utilized off-board, facility battery chargers.

The 12-V Titan auxiliary battery, manufactured by the General Battery Corporation, normally receives its charge from one of the onboard Lester chargers, while during baseline testing, the auxiliary battery was also recharged from a facility battery charger. The auxiliary battery is recharged by a 12-V alternator, belt-driven off the drive motor during vehicle operation.

SECTION V

TEST METHODOLOGY

For the purposes of this report, testing is divided into two general categories: track and chassis dynamometer. Track tests were limited to road load determination from coastdowns for the purpose of establishing dynamometer settings. The chassis dynamometer tests consisted of range determination at constant speeds of 40 km/h (25 mph) and 72 km/h (45 mph), for the J227a "B" and "C" schedules. These are discussed in more detail below. A more detailed discussion of the test methodology used for the "2 x 4" Program may be found in a companion report, Reference 5-1. The discussion included here is, in general, limited to those items unique to the Battronic Truck.

JPL operates a Test Facility at the Edwards Air Force Base which is located near Lancaster, California. At this facility, known as Edwards Tests Station (ETS), JPL has access to a semi-active Air Force runway 1829 m (6000 ft) in length. This runway was utilized for coastdown testing.

The steady speed and cyclic range tests were conducted in the chassis dynamometer portion of the JPL Automotive Test Facility. A twin roll Clayton dynamometer with 218 mm (8.6 in.) diameter rollers and direct-drive inertia weights available in 57 kg (125 lb) increments was used. This dynamometer is the type specified by the Environmental Protection Agency for exhaust emission certification testing.

The Clayton twin-roll type dynamometer used at JPL has only a single adjustment for the simulation of aerodynamic load. That is, the load can be set at only one value of vehicle speed. The loads at other speeds are fixed by the cubic variation of load as a function of roller velocity that is built into the dynamometer. In addition, the tire pressure and/or the tire loading (vehicle weight on the drive wheels) can be manipulated, within limits, so as to vary the tire/roller losses.

A. ROAD LOAD DETERMINATION AND DYNAMOMETER LOAD ADJUSTMENT

Determination of road load power requirements is a standard test specified in the SAE Test Procedure J227a. The intent of the SAE procedure is to define road load for reporting purposes, while in the context of this report, road load determination was used primarily for defining dynamometer adjustments.

After the road load determination was completed at ETS, the vehicle was moved to the dynamometer and the coastdown process repeated. First, the time required to coast from 32 to 16 km/h (20 to 10 mph) was matched to the track time by adjusting the tire pressure and/or tire loading. Over this velocity increment the aerodynamic portion of the total road load is small and the necessary tire adjustments are not masked by the aerodynamic variable.

Once the 32 to 16 km/h (20 to 10 mph) coastdown time was matched, the aerodynamic load was adjusted by means of the water brake absorber portion of the dynamometer. This is generally done over the velocity interval of 88 to 72 km/h (55 to 45 mph).

but can, in principal, be done at any velocity. As high a speed as practical is used so that the aerodynamic load is as large a part of the total as possible. Again, the time to coast between two speeds was matched to that obtained during the track test. The 32 to 16 km/h (20 to 10 mph) coastdown was repeated and the tire pressure/loading was adjusted if necessary. The two coastdowns were alternately performed until the two road times were matched as closely as possible.

After the "road" coastdown times were duplicated on the dynamometer, the resultant aerodynamic horsepower at 80 km/h (50 mph) was measured. Note that this was the first time that an actual power value was defined even though it was road load being duplicated. The dynamometer was then adjusted to this specific horsepower value before each subsequent test of the vehicle. A more detailed description of the coastdown and dynamometer process may be found in Reference 5-1. The averaged results of the ETS tests 2, 3, and 4 are listed in Table 5-1. Test #1 was discarded due to unacceptable wind conditions.

B. CHASSIS DYNAMOMETER INSTRUMENTATION

A relatively large general purpose data system is an integral part of the JPL Automotive Test Facility. This Integrated Data Acquisition and Control (IDAC) system is used to record data for all tests conducted on the chassis dynamometer. The digitally formatted energy data is sampled 10 times per second to permit good time resolution during the transient portions of a test. Each analog data channel is also sampled about 10 times a second. The data system is described in more detail in Reference 5-2.

Data recording is accomplished in two ways: high-speed printer (on paper) and magnetic tape. The bulk of the recording is done with the magnetic tape while the direct printing is used for a "quick look" immediately after test completion. Subsequent data reduction of the magnetic tapes provides a print-out of all data as well as plots of pertinent parameters.

Slices of data are acquired at various time intervals. The exact time within the test depends on the type of test. For instance, during constant-speed tests, data are recorded once every 30 s. For the driving schedule tests, in addition to the 30-s interval data, continuous recordings of two complete repetitions of the driving cycles (Figure 5-1) are made. These continuous recordings are intended to occur at four discrete levels of battery depth of discharge, however, the time at which these recordings occurred was specified in advance of the test. Therefore, the designation 0%, 40%, 80%, and 100% depth of discharge is approximate only. During some tests, the continuous recording at 100% depth of discharge was missed altogether because of the estimating process and the very rapid decay in battery voltage as 100% depth of discharge approached.

During the chassis dynamometer tests approximately 60 parameters were measured and recorded. The key measurements were those of voltage, current, energy, and power for the battery and motor armature, motor and drive shaft rotational speed, aerodynamic horsepower, vehicle velocity, distance traveled, and battery temperature. Each of these is discussed in more detail below.

Table 5-1. Battronic Truck Coastdown Results -- Average of all Tests

Velocity Mean, mph	Number of Points	Mean Time[a] Increment, s	Standard Deviation, s	S/M, %	Road Load Mean, hp	Road Load Standard Deviation, hp	Road Load S/M, %	Energy Required to Cruise at Mean Velocity Mean, kWh/M	Energy Required to Cruise at Mean Velocity Standard Deviation, kWh/M	Energy Required to Cruise at Mean Velocity S/M, %
50.0	20	12.4	0.6	4.7	28.44	1.32	4.6	0.424	0.020	4.6
45.0	20	13.7	0.8	5.9	23.22	1.51	6.5	0.385	0.025	6.5
40.0	20	16.0	0.6	3.5	17.69	0.62	3.5	0.330	0.012	3.5
35.0	20	18.6	0.9	4.8	13.27	0.63	4.7	0.285	0.013	4.7
30.0	49	22.6	1.9	8.3	9.41	0.77	8.1	0.234	0.019	8.1
25.0	40	27.1	2.3	8.4	6.56	0.57	8.7	0.196	0.017	8.7
20.0	32	31.1	3.8	12.1	4.60	0.62	13.5	0.172	0.023	13.5
15.0	30	36.6	4.7	12.7	2.93	0.39	13.1	0.146	0.019	13.1

[a]The time to coast between two fixed velocities (a ΔV of 10 mph) is determined. Thus, the time increment of 12.4 s at a mean velocity of 50 mph should be interpreted as follows. The vehicle required 12.4 s to coast from 55 mph to 45 mph. Twenty repeats of the nominal 50 mph test were conducted and a standard deviation of 0.6 s was noted.

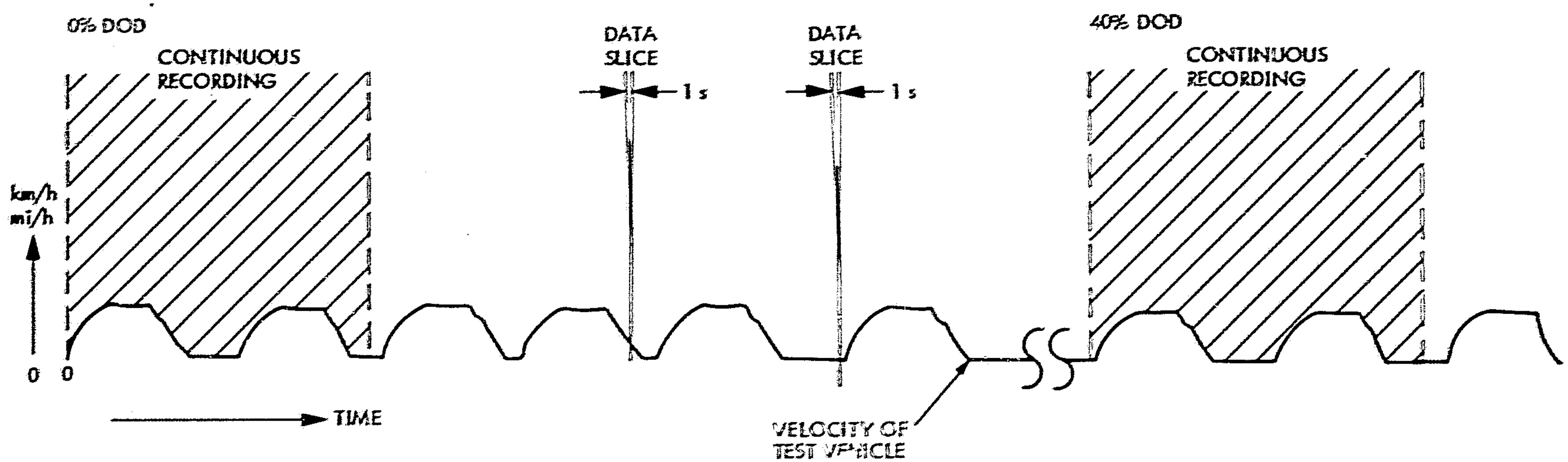

Figure 5-1. Typical Data Recording Format During Vehicle Range Test

1. Power Measurements (voltage, current, energy)

The power measurement system uses signals proportional to voltage and current, multiplies the current and voltage, and provides digital output signals proportional to bipolar power. Analog signals of the input current and voltages are also available. These analog signals are isolated from common-mode voltages and include both wideband (approximately 50 kHz) and filtered (approximately 10 Hz) output signals. The 50 kHz response outputs are primarily used for checkout, investigation of waveforms, and related activities. The low frequency signals are connected to the test facilities data system to provide recorded data of both voltage and current. The output signals proportional to power are recorded by both mechanical counters and the IDAC. Figure 5-2 shows the mechanical counters in a vehicle other than the Battronic Truck.

2. Motor and Drive Rotational Speed

During dyno testing, the rotational speed of the electric motor and drive shaft were recorded by using alternating strips of reflective and black tape on the shafts. A photo optical sensor was used to monitor the black-to-reflective tape transitions and thus provide a signal proportional to the shaft rotational speeds.

3. Vehicle Velocity and Distance Traveled

Each of the two dynamometer rolls is equipped with a digital transducer which produces a pulse proportional to each centimeter of distance traveled. These pulses are recorded as a rate (miles per hour) and integrated with a counter (miles). Although the pulse signals from both dynamometer rolls are recorded, only the data on the idle roll are used for reporting purposes. Data from the absorption roll are used for engineering information and to adjust the dynamometer aerodynamic load.

4. Torque and Aerodynamic Horsepower

The reactive torque which results from energy being dissipated in the dynamometer absorption unit is measured by a precision load cell. Using torque and dynamometer rotational speed the IDAC data system calculates horsepower in near real time (within 0.1 s). This permits accurate adjustments of the dynamometer aerodynamic horsepower.

5. Miscellaneous Measurements

Additional recorded measurements include battery temperature, motor case temperature, atmospheric pressure, and calibration voltages.

C. VEHICLE CONDITIONING AND WARM-UP

No vehicle warm-up was performed before the range tests. A warm-up was performed prior to all road load determination (coastdown) testing at ETS and

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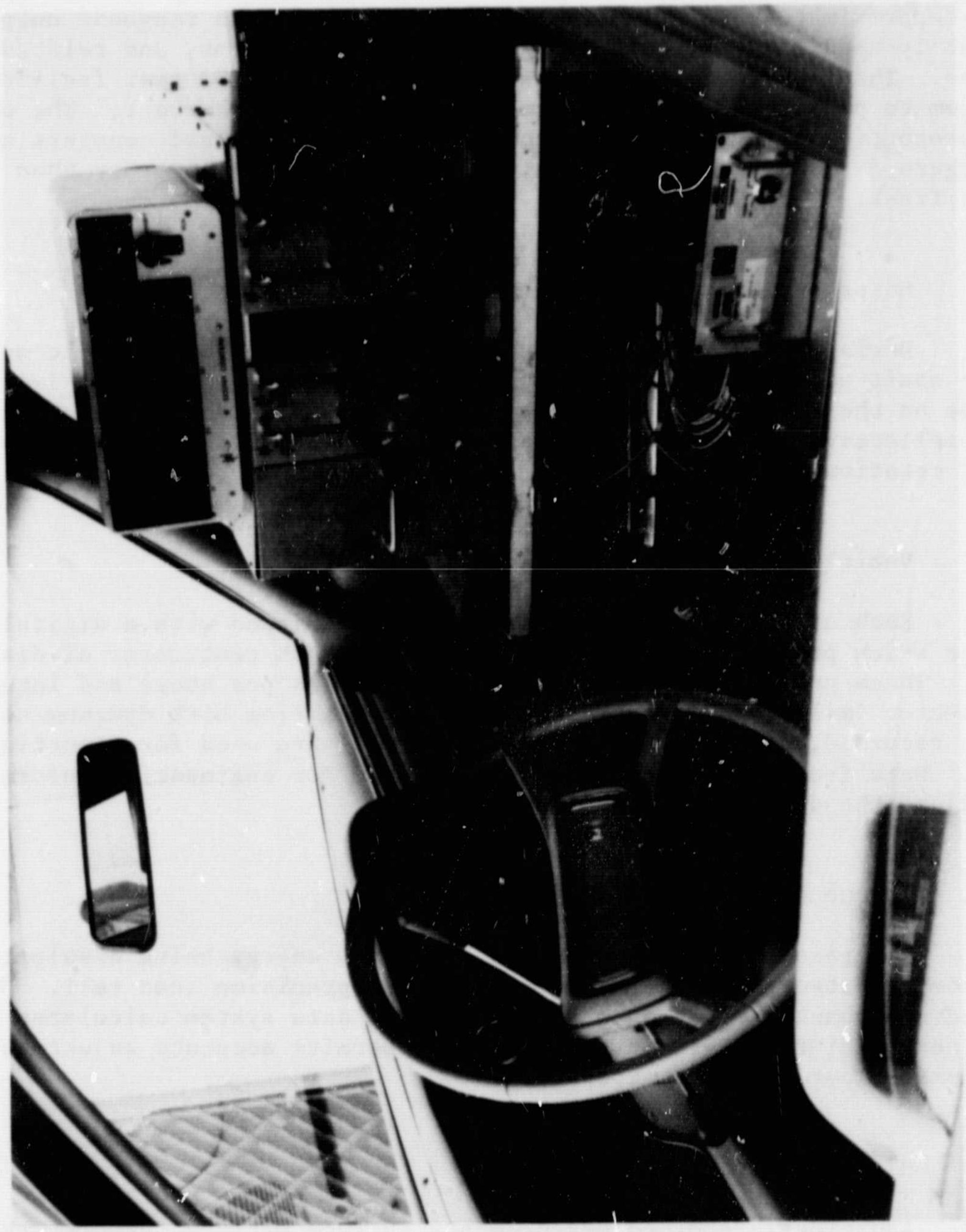

Figure 5-2. Power Measurement System

before the companion chassis dynamometer coastdowns. The warm-up at ETS was accomplished by towing the vehicle up and down the length of the runway at 40 to 56 km/h (25 to 35 mph) for approxiamtely 10 km (6 mi). The intent of this warm-up period was to bring the vehicle lubricants, wheel bearings, and tires to near their normal operating temperatures.

D. DYNAMOMETER TEST PREPARATIONS

A dynamometer warm-up was conducted prior to testing in the following manner: An IC engine-powered vehicle was operated on the dynamometer for 5 min at 80 km/h (50 mph) and an additional 5 min at 56 km/h (35 mph). The inertia weight setting corresponding to the Battronic test weights of 2608 kg (5750 lb) was then coupled to the dynamometer rollers. The warm-up vehicle was operated at a constant speed of 80 km/h (50 mph) and the dynamometer then adjusted to the specific horsepower value determined from the vehicle/dynamometer coastdown tests. Immediately following the warm-up, the test vehicle was winched onto the dynamometer, for the test. No test vehicle warm-up was performed prior to dynamometer testing.

Range at steady speed and maximum acceleration tests were performed as specified in the SAE Test Procedure J227a, supplemented by additional definition by JPL. The intent of the supplemental definitions was to make the schedules more precise. The details of the supplemental definitions may be found in Reference 5-1.

E. TEST TERMINATION CRITERIA

Three test termination criteria were used, depending on the nature of the test; i.e., constant speed or cyclic. Constant speed tests were ended when (1) the pack battery voltage decayed to an average of 1.3 V/cell (94 V for the total battery pack), for more than 5 s; (2) the batteries or motor temperature exceeded the limit specified by the manufacturer; or (3) the vehicle speed could not be maintained within 95% of the specified velocity. Criteria (1) and (2) were also employed for the cyclic tests, but a different velocity criteria was used. The cyclic tests were terminated when the acceleration portion of any cycle could not be completed within 2 s of the time specified by the procedure. In practice, the constant speed tests were terminated by the battery voltage criteria, while the cyclic tests were ended by a failure to meet the acceleration standard.

SECTION VI

TEST HISTORY

A. PRE-TEST ACTIVITIES

The Battronic Truck was received by JPL on 14 August 1979 from Battronic Industries. Upon receipt of the vehicle at JPL, a safety inspection was performed. This inspection preceded installation of the instrumentation and testing of the vehicle. The primary purpose of the inspection was to ensure that the vehicle was safe for use by the operating personnel and for all test-related purposes. For example, it was verified that the battery terminals were covered, all points of high voltage were shielded from accidental human contact, the propulsion system was electrically isolated from the vehicle chassis, and all batteries were adequately constrained. In addition, the conventional vehicle safety equipment (horn, lights, turn indicators, etc.) was verified to be operational, and the battery compartment ventilation system was checked for proper operation.

Prior to start of the test phase, the wheel bearings and suspension system were inspected and lubricated. All wheels were balanced and aligned according to the manufacturer's specifications. The vehicle was weighed and the load distribution between the front and rear axles defined. From this, the additional weight required (primarily for coastdown testing) to bring the vehicle to the test weight of 2608 kg (5750 lb) was determined and distributed appropriately.

Minor modifications were made to the vehicle by JPL in preparation for testing. The existing front bumper was replaced with one of special design for the Battronic Pickup. This heavy-duty bumper allowed safe towing of the vehicle during the high-speed coastdown testing. Quick disconnect connectors were installed between the battery packs and the motor/controller. This provides a safe, convenient way to isolate the batteries from the motor and controller during maintenance and repair, and also allows a convenient place to connect facility batteries for non-test operation of the vehicle on the chassis dynamometer. Current sensors (shunts) were installed on the negative cable side of the battery pack, the motor armature, and the motor field. Voltage sense points were connected to the positive cable side of each of the twenty-four propulsion batteries. Temperature sensors were installed on the traction motor, controller, battery case, and into the electrolyte of several cells. In addition, a shunt was installed within the vehicle for use with the external battery charger that was used during the test program.

Metal shield cowls were fitted around the controller unit to protect it from possible mechanical damage during any maintenance work. A similar shield was added just under the dashboard to provide protection of the exposed wire harness located there. An internal requirement that the tires have a minimum of 640 km (400 mi) road wear before testing was satisfied while the vehicle was undergoing tests at the U.S. Army Mobility Equipment Research and Development Command (MERADCOM).

The detailed battery history, prior to delivery of the vehicle to JPL, is unknown. However, at the time of vehicle delivery all battery modules had low electrolyte levels. Two of the modules did not perform as expected even after adjustment of the electrolyte level and had to be replaced prior to the JPL tests.

B. BATTERY CHARGING

Vehicle range is dependent on several factors with battery energy being one of the major items. In turn, battery energy is directly dependent on, among other things, the particular charging procedure that is used. The procedure used for the tests of the Battronic Truck was designed to provide a consistent, 100% charge at the start of each range test. Secondarily, the procedure was also designed to be as efficient as possible and still meet the consistency requirements. The efficiency aspect also leads to minimum heating of the battery electrolyte, and thus reduces the time for subsequent temperature stabilization (see below). Note that battery life was not a primary consideration in the design of the JPL charge procedure. In fact, because the procedure is very nearly an equalization charge (albeit more efficient than the usual equalization), long-term battery life could well be shortened by use of the procedure. No tests were performed to evaluate the effect of the charging procedure on battery life.

The battery charging procedure employed for all range tests consisted of the following steps:

(1) Charge the batteries at a constant 25 A rate until the average cell voltage is 2.46 V/cell corrected to an electrolyte temperature of 26°C (80°F).

(2) When the average cell voltage is 2.46 V/cell, switch from current control to voltage control. Maintain the temperature compensated cell voltage at 2.46 V/cell and allow the charge current to taper (i.e., decrease) for 6 hours.

(3) Allow the battery electrolyte to cool to 21 ± 2°C (70 ± 5°F) before a test is begun.

The purpose of the third step of the charging procedure was to eliminate battery electrolyte temperature as a source of range variation. All else being equal, a "hot" lead-acid battery will deliver more energy than a "cold" one. Typical electrolyte temperatures at the end of step (2) were more than 38°C (100°F). In order to start a test with an electrolyte temperature of 21 ± 2°C (70 ± 5°F) the vehicle was placed in a temperature-controlled room for 24 hours. The cool air of the room was circulated over the batteries by means of a fan. Because of the large thermal mass of the battery pack and the packaging of the batteries, these steps were required to achieve the desired battery temperature.

C. ETS ACTIVITIES

A total of thirty high-speed and forty low-speed coastdown tests were accomplished at ETS. The vehicle was then returned to JPL for evaluation by dynamometer testing.

D. DYNAMOMETER ACTIVITIES

After returning the Battronic Truck to JPL, the vehicle was prepared for operation on the JPL dynamometer. The original JPL test requirements for the "2 x 4" vehicles specified that the following tests would be performed:

(1) Range at steady speeds of 56 km/h (35 mph) and 88 km/h (55 mph).

(2) Driving cycle range for the J227a "B" and either "C" or "D" schedules, depending on the vehicle's capability.

The requirement for range at a steady speed of 88 km/h (55 mph) was changed to a velocity of 72 km/h (45 mph) because the maximum velocity attainable during dyno/vehicle operation was 80 km/h (50 mph). In addition, the 56 km/h (35 mph) test was replaced by one at 40 km/h (25 mph) in order to produce a better spread in the data.

SECTION VII

TEST RESULTS

This section presents the results of both the track (ETS) and dynamometer tests. There were three major test types: range at constant speed, range under the SAE J227a driving schedules "B" and "C", and road load determination tests. All tests of the Battronic Truck were conducted using Exide EV 106 lead acid batteries. All data recording was accomplished in customary U.S. units, but are reported in this section in both S.I. (metric) and U.S. units. Appendix A is a summary of all track and dynamometer test data.

A. RANGE AT CONSTANT SPEED TESTS

Two each constant speed tests at 72 km/h (45 mph), and 40 km/h (25 mph) were conducted on the dynamometer at the JPL Automotive Test Facility. Speed was held constant to within $\pm 5\%$ of the nominal value and the tests were terminated according to the criteria outlined in Section V-E. The test data are shown in Tables 7-1 and 7-2.

Tables 7-1 and 7-2 show the expected trend of improved energy economy as velocity is reduced. The range, energy consumption, total energy and charge expended, and charge/discharge efficiencies all manifest this trend. There is a gross improvement of 100% in the range, a lesser but significant improvement of approximately 40% in the energy consumption, the consumed energy, and charge values, and a modest increase of approximately 10% in the charge/discharge efficiencies as the speed is reduced from 72.4 km/h (45 mph) to 40.2 km/h (25 mph).

For both steady-state tests there was a slightly higher beginning battery temperature condition for the second of each of the tests. The two 25 mph tests were performed with a $3^{o}F$ temperature difference, while for the 45 mph tests, the temperature difference was $9^{o}F$. At the same time, there was virtually no increase in the respective ranges as is generally expected. The rule of thumb criteria is that for each $1^{o}C$ change in battery temperature there should be a 1% change in range.

B. DRIVING CYCLE RANGE TESTS

To simulate "normal" operation of an electric vehicle, i.e., stop-and-go driving, the SAE has established four driving cycles for electric vehicles. The driving cycles exercise the vehicle in a near "normal" manner, but more importantly are intended to lead to test repeatability and standardization. The exact requirements of these cycles are presented in Reference 2-1. For the purposes of the JPL tests, additional definition has been added to these driving schedules. The addition consists of defining the velocity of the acceleration, coast, and brake segments at 1-s intervals. The basic J227a procedure defines only the end points of each segment. The form of the cycles used at JPL are described in detail in Reference 5-1. Three each of the schedule "B" and "C" were completed. All tests were terminated as a result of

Table 7-1. Battronic Truck -- 72 km/h (45 mph) Constant Speed Test

English Units

Test No.	Range, mi	Cycles Driven	Battery Energy, kWh		Battery Energy Consumption, kWh/mi	Battery Energy Recharge, kWh	Battery, Ah		Battery Temp[a], °F		Battery Charge/Discharge Efficiency, %	
			Out	(Regen) In			Test	Recharge	Pre Test	Post Test	Wh	Ah
4	24.36	--	12.28	0.013	0.504	23.92	100.5	142.7	65	92	51.4	70.4
7	24.26	--	12.30	0.012	0.507	23.16	101.1	140.1	74	102	53.0	72.1

Standard International Units

Test No.	Range, km	Cycles Driven	Battery Energy, kWh		Battery Energy Consumption, MJ/km	Battery Energy Recharge, MJ	Battery, Ah		Battery Temp[a], °C		Battery Charge/Discharge Efficiency, %	
			Out	(Regen) In			Test	Recharge	Pre Test	Post Test	Wh	Ah
4	39.20	--	44.22	0.047	1.12	86.11	100.5	142.7	18.3	33.3	51.4	70.4
7	39.04	--	44.30	0.043	1.13	83.36	101.1	140.1	23.3	23.3	53.0	72.1

[a]Average of five (5) instrumented batteries.

Table 7-2. Battronic Truck -- 40 km/h (25 mph) Constant Speed Test

English Units

Test No.	Range, mi	Cycles Driven	Battery Energy, kWh Out	Battery Energy, kWh (Regen) In	Battery Energy Consumption, kWh/mi	Battery Energy Recharge, kWh	Battery, Ah Test	Battery, Ah Recharge	Battery Temp[a], °F Pre Test	Battery Temp[a], °F Post Test	Battery Charge/Discharg Efficiency, % Wh	Battery Charge/Discharg Efficiency, % Ah
3	48.17	--	17.79	0.003	0.369	30.66	142.5	186.6	70	93	58	76.3
8	48.26	--	17.77	0.005	0.368	29.49	140.8	181.5	73	97	60.3	77.6

Standard Internatonal Units

Test No.	Range, km	Cycles Driven	Battery Energy, kWh Out	Battery Energy, kWh (Regen) In	Battery Energy Consumption, MJ/km	Battery Energy Recharge, MJ	Battery, Ah Test	Battery, Ah Recharge	Battery Temp[a] °C Pre Test	Battery Temp[a] °C Post Test	Battery Charge/Discharge Efficiency, % Wh	Battery Charge/Discharge Efficiency, % Ah
3	77.47	--	64.06	0.028	0.826	110.4	142.5	186.6	21.1	33.8	58	76.3
8	77.66	--	63.99	0.018	0.824	106.2	140.8	181.5	22.7	36.1	60.3	77.6

[a]Average of five (5) instrumented batteries.

the vehicle being unable to match the acceleration ramp in the prescribed time. Tables 7-3 and 7-4 summarize the results of those tests. The mean range of the "B" cycle tests was 27.88 mi with a standard deviation of 6.7%; the respective values for the "C" cycle tests were 17.27 mi and 11%.

The differences in range and battery energy for the "B" and "C" cycles cannot be attributed to differences in battery temperature levels. Ordinarily, a 1% range variation can be expected for each $1^{o}C$ ($1.8^{o}F$) change in battery temperature. Using this rule of thumb a maximum 1.6% of the range variation can be attributed to the change in temperature between these two runs. The remainder of the performance variation is a reflection of the inherent repeatability of the vehicle (most likely battery effects) and of the test process.

As can be seen from Tables 7-3 and 7-4, the energy returned to the batteries by regeneration was nil. This resulted from the fact that the regeneration feature is activated by the initial brake pedal pressure. During the coast and brake phases of the schedules, the brakes were not required to match the prescribed time/velocity curves. In fact, some use of the accelerator pedal was required. The rolling resistance of the vehicle was larger than the retarding force required to match the schedule decelerations. The net effect was no regeneration. No attempt was made to devise a special test to evaluate the regeneration capability of the Battronic Truck.

Table 7-3. Battronic Truck — "B" Cycle Test

English Units

Test No.	Range, mi	Cycles Driven	Battery Energy, kWh Out	Battery Energy, kWh (Regen) In	Battery Energy Consumption, kWh/mi	Battery Energy Recharge, kWh	Battery, Ah Test	Battery, Ah Recharge	Battery Temp[a], °F Pre Test	Battery Temp[a], °F Post Test	Battery Charge/Discharge Efficiency, % Wh	Battery Charge/Discharge Efficiency, % Ah
2	25.7	125	14.81	0.02	0.575	24.4	—[b]	175.2	69	107	50.4	—[b]
5	28.7	139	16.78	0.21	0.584	31.4	144.5	189.2	71	105	53.8	70.6
9	29.2	142	16.78	0.17	0.575	30.3	142.5	185.1	68	103	55.4	76.9

Standard International Units

Test No.	Range, km	Cycles Driven	Battery Energy, kWh Out	Battery Energy, kWh (Regen) In	Battery Energy Consumption, ms/km	Battery Energy Recharge, ms	Battery, Ah Test	Battery, Ah Recharge	Battery Temp[a], °C Pre Test	Battery Temp[a], °C Post Test	Battery Charge/Discharge Efficiency, % Wh	Battery Charge/Discharge Efficiency, % A-h
2	41.44	125	53.32	0.849	1.28	87.84	—[b]	175.2	20.5	41.6	50.4	—[b]
5	46.22	139	60.42	0.749	1.31	112.2	144.5	189.2	21.6	40.5	53.8	70.6
9	46.97	142	60.42	0.749	1.29	109.1	142.5	185.1	20.0	39.4	55.4	76.9

[a]Average of five (5) instrumented batteries.

[b]Instrumentation hardware problems; no data obtained for this parameter.

Table 7-4. Battronic Truck — "B" Cycle Test

English Units

Test No.	Range, mi	Cycles Driven	Battery Energy, kWh: Out	Battery Energy, kWh: (Regen) In	Battery Energy Consumption, kWh/mi	Battery Energy Recharge, kWh	Battery, Ah: Test	Battery, Ah: Recharge	Battery Temp[a], °F: Pre Test	Battery Temp[a], °F: Post Test	Battery Charge/Discharge Efficiency, %: Wh	Battery Charge/Discharge Efficiency, %: Ah
1	15.20	43	9.4	0.161	0.622	19.79	—[b]	118.1	71	108	47.8	—[b]
6	19.17	54	11.91	0.207	0.621	23.38	102.5	144.3	72	105	50.9	72.5
10	17.43	49	10.72	0.189	0.615	35.16[c]	92.3	105.3	70	103	30.5[c]	44.9

Standard International Units

Test No.	Range, km	Cycles Driven	Battery Energy, kWh: Out	Battery Energy, kWh: (Regen) In	Battery Energy Consumption, MJ/km	Battery Energy Recharge, MJ	Battery, Ah: Test	Battery, Ah: Recharge	Battery Temp[a], °C: Pre Test	Battery Temp[a], °C: Post Test	Battery Charge/Discharge Efficiency, %: Wh	Battery Charge/Discharge Efficiency, %: Ah
1	24.46	43	34.1	0.579	1.39	71.24	—[b]	118.1	21.6	42.2	47.8	—[b]
6	30.85	54	42.9	0.745	1.39	84.18	102.5	141.3	22.2	40.5	50.9	72.5
10	28.05	49	389.6	0.680	1.38	126.6[c]	92.3	205.3	21.1	39.4	30.5[c]	44.9

[a]Average of five (5) instrumented batteries.

[b]Instrumentation problem; no data obtained for this parameter.

[c]Excessive energy consumed because of a timer failure in the charger.

SECTION VIII

DISCUSSION AND PROBLEMS

A. GENERAL OBSERVATIONS

The basic design of this vehicle indicates that its intended use is for transporting medium-weight commercial industrial loads at modest speeds. In its normal internal combustion engine (ICE) configuration, the Battronic Truck would probably carry maximum loads upwards of 408 to 544 kg (900 to 1200 lb). In its configuration as an electrically propelled vehicle the payload is reduced to 227 kg (500 lb).

Nominal road load power at 72 km/h (45 mph) was 13.4 kW (18 hp). This is primarily the result of its rather rectangular configuration (and associated poor aerodynamic performance) and 5000 lb curb weight. This level of road load power is not surprising, considering the intended vehicle application together with the physical attributes noted above. The vehicle and its equipment did not develop any particularly major or recurring problems. The few such events are discussed further. A limited ability to handle large changes in dynamic loads would appear to be a characteristic of this vehicle because of the relatively low-ratio transmission and its restriction to only two gears, at 1.1 and 1.36 for the high and low ranges, respectively.

As mentioned in Section IV, the Battronic Truck's electric motor adapts to variable loads through pulse-width modulation of the series field-armature circuit. The components are sized to handle current flows of 500 A, although the controller includes a current limit of 450 A. In addition, motor protection is provided by a 350-A time-delay fuse, and a controller current output limit of 450 A.

B. DRIVING CHARACTERISTICS

The location of all control instruments, seemed suitable for quick reference and easy access. Visibility was normal and there were no particular blindspots.

As stated earlier, the lack of a clutch allowed shifting of the transmission gears only while the vehicle was stationary. This created a problem only for the coastdown tests because the lack of a positive neutral position made it difficult to identify the neutral position. For normal use of the vehicle it was not a problem.

C. PROBLEMS

The problems experienced were not catastrophic component failure, but might be better described as vehicle idiosyncrasies. Because they had no effect on the test results, but merely presented some operational problems, they are not discussed here.

D. ENERGY USAGE

As an aid to understanding the characteristics of the Battronic Truck, energy usage was analyzed as a function of the five phases of the SAE Procedure J227a Driving Schedules (acceleration, cruise, coast, brake, and idle). Figures 8-1 and 8-2 depict the energy division for a single SAE J227a "B" and "C" driving cycle, respectively, and the effect of battery depth of discharge is shown in Figures 8-3 and 8-4. As might be expected for a vehicle of this weight, over half of the total energy drawn from the batteries was expended during acceleration, and another large part was used during cruise.

E. COMPARISON TO OTHER ELECTRIFIED VEHICLES AT STEADY SPEED

A qualitative evaluation of the Battronic Truck has been made by comparing the performance described in this report with the results reported in Reference 8-1. Reference 8-1 contains test results for 22 electric vehicles that were tested specifically for the purpose of assessing the state of the art of electric vehicles in 1977.

Figure 8-5, a plot of vehicle range for constant-speed operation versus vehicle speed, consists of data reported here superimposed on a figure copied from Reference 8-1. The vehicles from Reference 8-1 fell into two broad categories. The average of each of these two categories is denoted by light, dashed lines. As can be seen by the heavy line representing the Battronic Truck, its range is approximately that of the majority of the vehicles tested in 1977. It should be emphasized that the type of comparison shown in Figure 8-5 is qualitative, but at the same time it seems safe to conclude that the range performance of the Battronic Truck is comparable to the majority of the vehicles evaluated for the 1977 state-of-the-art report.

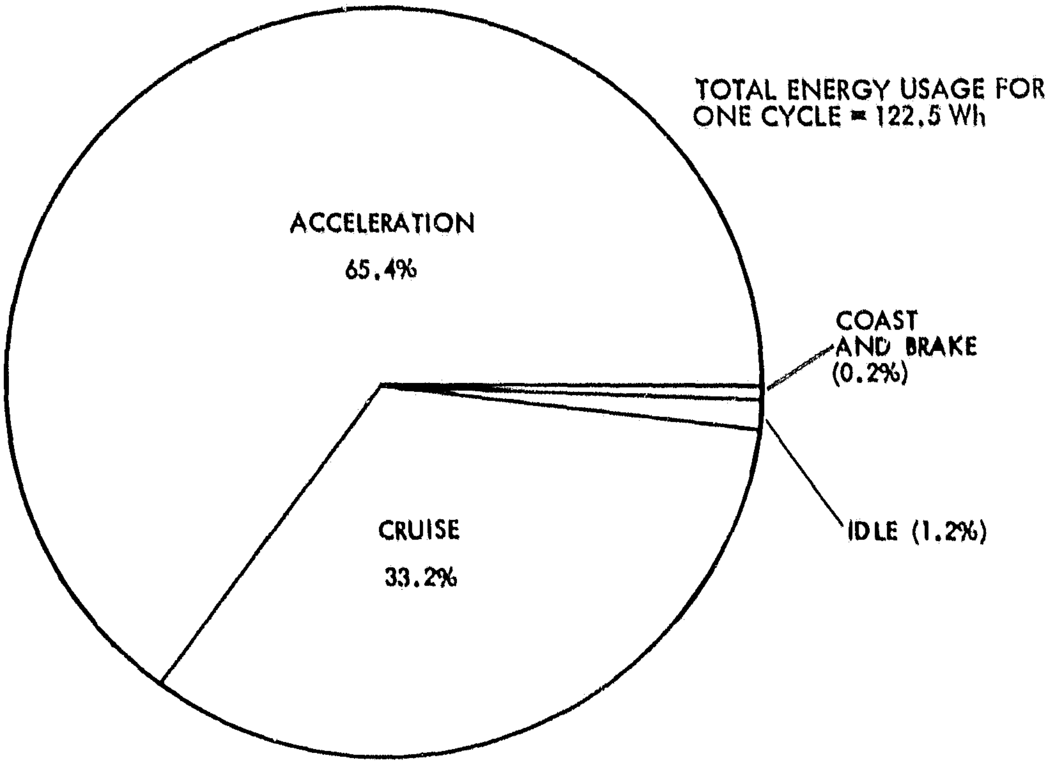

Figure 8-1. Energy Usage for Driving Cycle "B" @ 40% Depth of Discharge

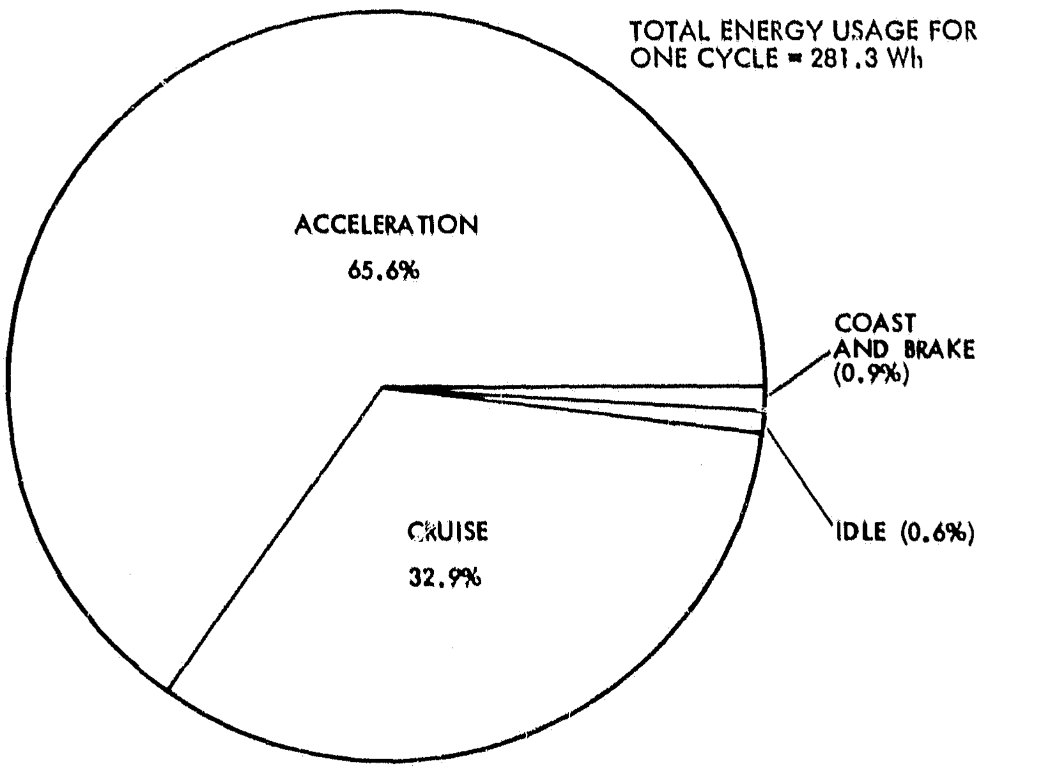

Figure 8-2. Energy Usage for Driving Cycle "C" @ 40% Depth of Discharge

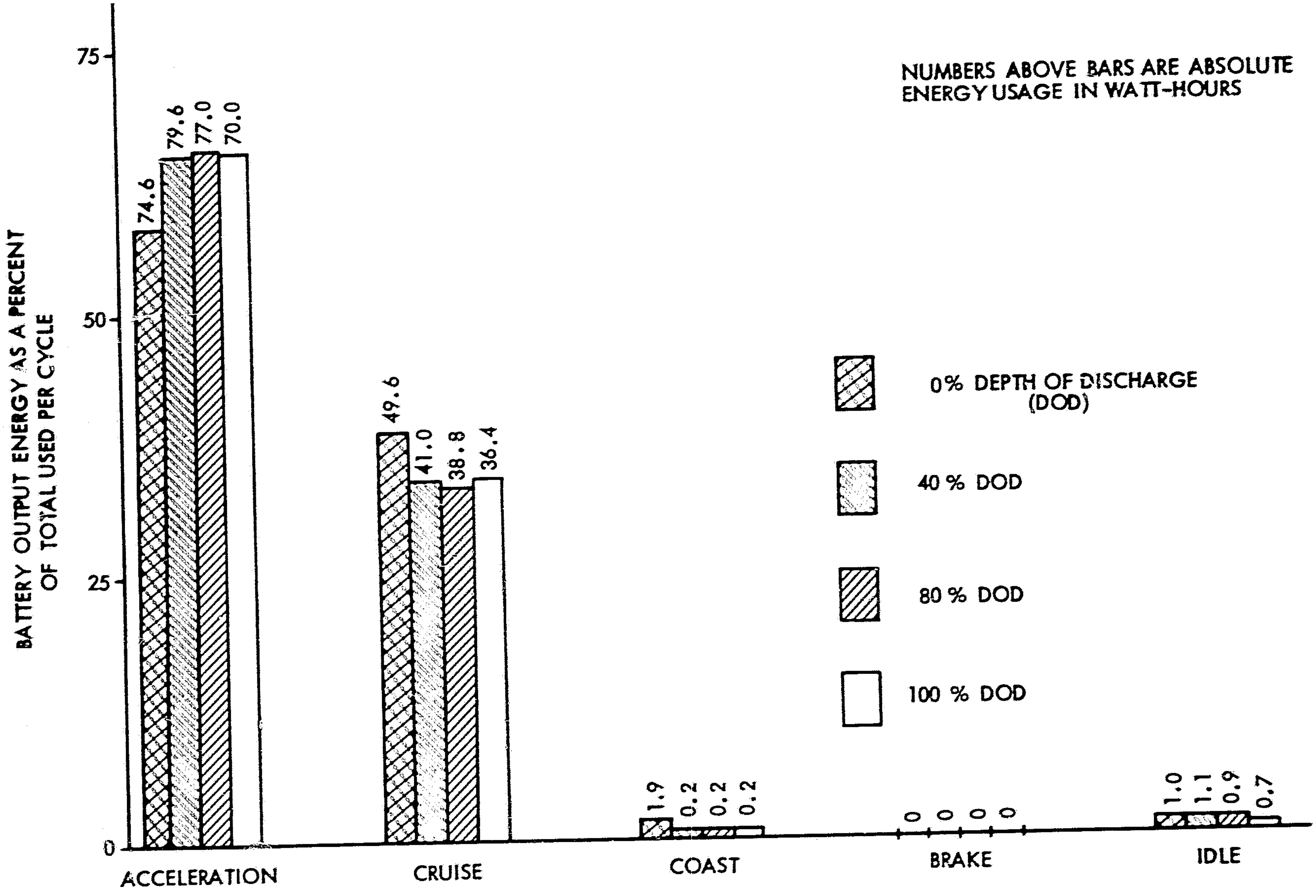

Figure 8-3. Schedule "B" Battery Energy Usage as a Function of Depth of Discharge

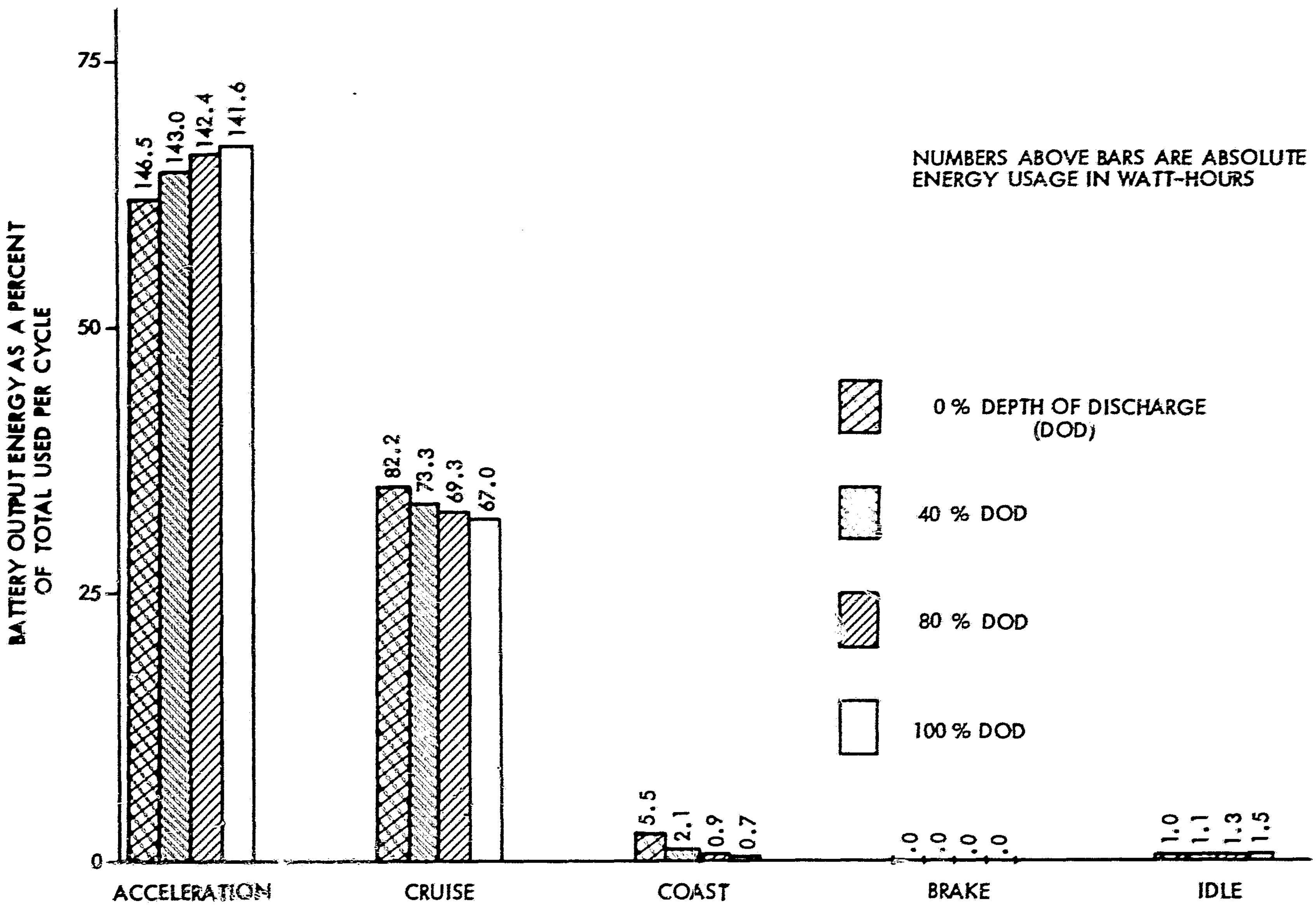

Figure 8-4. Schedule "C" Energy Usage as a Function of Battery Depth of Discharge

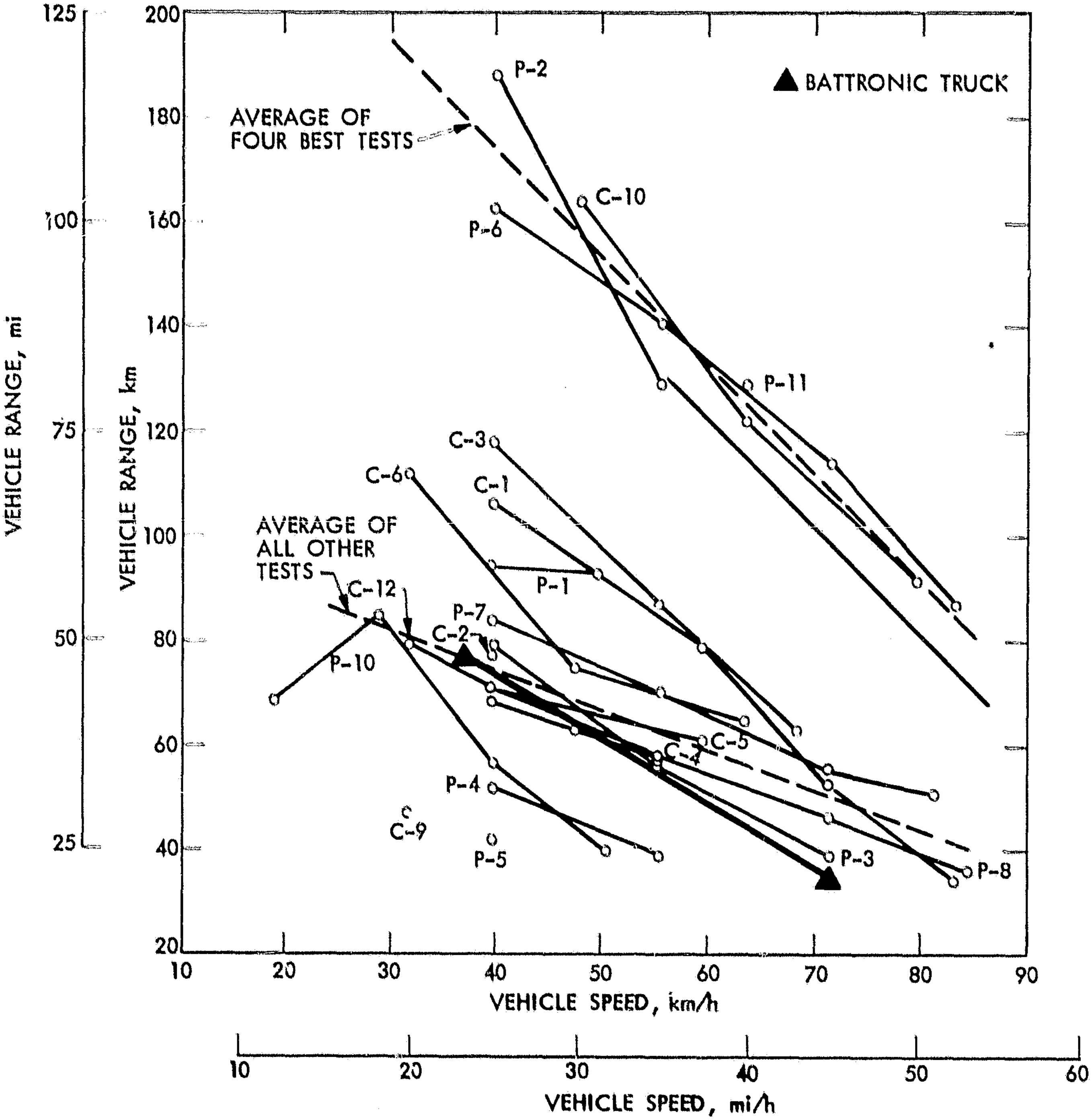

Figure 8-5. Vehicle Range as a Function of Speed

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5-1. Price, T.W., Shain, T.W., and Bryant, J.A., Vehicle Test Report: South Coast Technology Electric Conversion of a Volkswagen Rabbit, JPL Publication 81-28. Jet Propulsion Laboratory, Pasadena, California, February 1981.

5-2. Griffin, D.C., and Bryant, J.A., "Data Acquisition System for Electric Vehicle Tests," Proceedings of the IAS Annual Meeting, IEEE Industry Applications Society, September 1980.

8-1. State-of-the-Art Assessment of Electric and Hybrid Vehicles, NASA TM-73756, Lewis Research Center, Cleveland, Ohio, September 1977.

APPENDIX A

TEST DATA SUMMARY

Battronic 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	1.98	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)	9.5	14.8	17.8	12.3	16.8	11.9	12.3	17.8
BATTERY REGEN. ENERGY (KWH)	0.16	0.24	0.01	0.01	0.21	0.21	0.01	0.00
BATTERY REGEN. ENERGY (%)	1.7	1.6	0.0	0.1	1.2	1.7	0.1	0.0
BATTERY DISCHARGE (AMP - HOURS)	N.A.	N.A.	142.4	100.5	144.8	102.5	101.1	140.0
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	77.0	75.7	90.5	75.9	82.0	89.0	74.5
ODOMETER READING (MILES)	683.1	700.1	729.5	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	60.26
BATTERY RECHARGE AMPERAGE EFFICIENCY(%)	N.A.	N.A.	76.3	70.4	78.6	72.6	72.1	77.6
BATTERY TEMP. BEFORE (DEG F)	71.2	68.8	70.0	65.0	71.4	72.2	74.8	73.2
BATTERY TEMP. AFTER (DEG F)	108.4	107.2	92.6	92.4	105.8	105.2	102.0	96.8

* COMMENTS

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OF POOR QUALITY

Battronic Truck

TEST NUMBERS	9	10	11
TEST DATE	03/19/80	03/21/80	03/24/80
TEST TYPE	B	C	C
BATTERY TYPE	PB-A	PB-A	PB-A
BATTERY	EV-106	EV-106	EV-106
BATTERY ENERGY ECONOMY (MI/KWH)	1.74	1.63	1.64
RANGE (MILES)	29.2	17.4	17.1
BATTERY DISCHARGE ENERGY (KWH)	16.8	10.7	10.5
BATTERY REGEN. ENERGY (KWH)	0.17	0.19	0.18
BATTERY REGEN. ENERGY (%)	1.0	1.8	1.8
BATTERY DISCHARGE (AMP - HOURS)	152.5	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)	12.66	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	30.60	0.00
BATTERY RECHARGE AMPERAGE EFFICIENCY(%)	77.0	44.9	N.A.
BATTERY TEMP. BEFORE (DEG F)	68.2	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