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VEHICLE PERFORMANCE TESTS OF THE FORD/GE FIRST GENERATION SINGLE-SHAFT (ETX-I) ALTERNATING CURRENT PROPULSION SYSTEM

R. L. CRUMLEY
R. D. MACDOWALL
J. E. HARDIN
A. F. BURKE

Idaho National Engineering Laboratory

U.S. Department of Energy • Idaho Operations Office

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EG&G Idaho, Inc.
Idaho Falls, Idaho 83415

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SUMMARY

The ETX-I test vehicle, which is powered by the single-shaft, alternating current (AC) electric powertrain developed by Ford and General Electric and the Lucas Chloride tubular plate lead-acid battery, was tested in the Idaho National Engineering Laboratory (INEL) Electric Dynamometer Laboratory. The characteristics of the vehicle and powertrain are presented in Tables S-1 and S-2. The tests indicated that the vehicle operates reliably over a range of constant speeds up to 88 km/h and over various driving cycles including the Federal Urban Driving Cycle (FUDS). The driveability of the vehicle was excellent for all driving modes-acceleration, deceleration, and cruise.

The Lucas Chloride ETX-I battery was tested in the INEL Battery Laboratory. The battery was characterized for constant current, constant power, and Simplified Federal Urban Driving Cycle (SFUDS) discharges before and after it was used to power the ETX-I vehicle in the dynamometer tests. The characterization tests indicated that the battery capacity was 91 Ah at the C/3 rate before the vehicle tests and that the capacity decreased by 10 to 15% during the vehicle tests (75 cycles). Lucas Chloride tests of the battery indicated a rating of 98 Ah at the C/3 rate. The capacity degradation during the INEL tests indicates it is unlikely that the battery life goal of 800 to 1000 cycles will be met. The FUDS and SFUDS tests of the ETX-I battery showed that the battery could provide a power of 45 to 50 kW at 100% State-of-Charge (SOC), 40 kW at 50% SOC, and 30 kW at 20% SOC, where SOC is based on a battery capacity of 70 Ah. At low states-of-charge (less than 30%), the power capacity of the battery was significantly less than the design goal of 40-45 kW. In general, the ETX-I battery was found to have higher capacity than other lead-acid batteries at moderate discharge rates, but its higher internal resistance, especially at low states-of-charge, precluded the use of all of the additional capacity for driving schedules requiring high power.

The ETX-I test vehicle was tested at INEL on the dynamometer at constant speeds between 40 and 88 km/h and on the J227 C and D, FUDS, and SFUDS driving cycles. The test results are summarized in Table S-3.

For constant speed, the energy consumption of the vehicle varied from 128 Wh/km at 40 km/h to 157 Wh/km at 88 km/h. The energy consumptions for the J227 C and D cycles were 197 and 176 Wh/km, respectively, and for the FUDS and SFUDS, the energy consumption was about 197 Wh/km. The energy consumption for the ETX-I measured at INEL was 10-15% higher than that reported by Ford. A portion of the difference (about 7%) is because of higher test weight (1705 versus 1590 kg) used in the INEL tests. The range of the ETX-I, at constant speed, varied from 128 km at 48 km/h to 67 km at 88 km/h. The range on the cycle driving schedules was about 60 km with little variation between the different schedules. Thus, the INEL data indicates that the ETX-I did not meet the goals of 160 Wh/km and 90 km for energy consumption and range, respectively, on the FUDS cycle set at the outset of the program. Comparisons of the energy consumption values for the ETX-I and the ETV-I show that the energy consumption of the ETX-I is 20 to 35% higher than the ETV-1; with the greatest differences being at the lower vehicle speeds. The higher energy consumption of the ETX-I results in it having a shorter range than the ETV-1 tested with the JCI Phase 3 Gel/cell batteries for all driving schedules. If the ETX-I battery were used in the ETV-1, the range of the ETV-1 would be increased by 10 to 15% above that measured using the same weight of Phase 3 Gel/cell batteries.

Acceleration tests of the ETX-I on the dynamometer resulted in acceleration times of 7.4 sec for 0 to 48 km/h and 21.3 sec for 0 to 80 km/h. These acceleration times agreed well with those measured by Ford on the track and were within 1 or 2 sec of the goals of the program. The acceleration of the ETX-I for speeds up to about 72 km/h (45 mph) was better than any other vehicle tested at the INEL, including the ETV-1. At higher vehicle speeds, the maximum power of the ETX-I motor began to decrease and as a result, the acceleration rates of the ETX-I were lower than those of the ETV-1.

The ETX-I test vehicle is compared in Table S-4 with other electric vehicles tested in the INEL Electric Vehicle Dynamometer Laboratory. Energy consumption, range, and acceleration time data are given in the table as well as vehicle and battery specifications for each case.

Table S-1. ETX-I TEST VEHICLE CHARACTERISTICS

Test weight (kg)	1705
Rolling Resistance (kg/kg)	0.0097
Drag Coefficient	0.42
Projected Frontal Area (m2)	1.775
Battery System Weight (kg)	634
Peak Motor Power (kW)	43

Table S-2. ETX-I POWERTRAIN CHARACTERISTICS

Motor	
Type	Three-phase AC induction
Peak Power (kW)	43 at 185 V, 34 at 153 V
Maximum Speed (RPM)	9000
Maximum torque (N-m)	95
Control method	Sinusoidal Current
Developer	General Electric Co.
Transmission	
Type	2-speed Automatic
Gear Ratios	
First	15.52
Second	10.15
Developer	Ford Motor Co.
Battery	
Type	Tubular Lead-acid
Weight (kg)	
Modules (16*12V)	520
System	634
Voltage (Nominal)	192
Capacity	
Ah at C/3	98
kWh at C/3	18
Developer	Lucas Chloride

TABLE S-3 ETX-I SUMMARY TEST RESULT

Test Type	Range (km)	Energy Consumption (Wh/km) ac*	System (dc[a])	Gross (dc)	Net (dc)	Gross[a] (dc)	Net[a] dc	Number of Tests
48 km/h	125.67	204	183	126	126	129	129	4
64 km/h	101.52	257	231	133	132	135	134	4
88 km/h	66.64	331	295	160	160	161	161	4
D-Cycle parallel regen	59.47	334	302	200	182	204	186	4
D-Cycle parallel regen (non continuous)	60.61	422	376	201	182	205	186	3
D-Cycle split regen	58.04	358	320	198	177	202	181	2
D-Cycle no regen	52.76	381	339	201	201	204	204	2
C-Cycle parallel regen	63.20	359	322	211	197	217	203	3
C-Cycle parallel regen (non continuous)	65.14	414	341	209	194	214	199	2
C-Cycle split regen	64.88	333	300	212	193	219	201	2
C-Cycle no regen	63.09	399	351	216	216	223	223	2
FUDS parallel regen	61.88	381	344	222	204	229	211	4
FUDS split regen	59.63	354	322	222	201	229	208	2
S-FUDS parallel regen	61.96	429	382	210	196	218	204	2

Acceleration - Average time (s) and Battery SOC of two tests.

	100% SOC	54% SOC	33% SOC	11% SOC
0-48 km/h	7.4	8.4	9.3	10.9
40-80 km/h	16.0	17.9	20.8	33.4
0-80 km/h	21.3	23.9	27.7	40.8
0-88 km/h	29.8	33.5	39.7	59.5
Peak Battery Power, Average (kw)	45.3	39.4	36.5	28.8
Battery Volt Range, Average (v)	209 to 164	199 to 156	195 to 145	189-133V

Energy Consumption Definitions

$$\text{ac} = \frac{\text{ac Energy to Charger for Recharge}}{\text{Distance Traveled}} \qquad \text{Vehicle dc Gross} = \frac{\text{dc Energy from Battery While Driving (not including Regen Benefit)}}{\text{Distance Traveled}}$$

$$\text{System dc} = \frac{\text{dc Energy From Charger for Recharge}}{\text{Distance Traveled}} \qquad \text{Vehicle dc Net} = \frac{\text{dc Energy from Battery While Driving including Regen Benefit}}{\text{Distance Traveled}}$$

a. Includes auxiliary battery energy used during the test

TABLE S-4 INEL ELECTRIC VEHICLE TESTING SUMMARY

VEHICLE SPECIFICATIONS			
Vehicle Designation	Bedford Van	Eaton AC-3	Eaton DC
Weight (kg)			
Test	3490	1641	1723
Curb [a]	2658	1352	1588
Gross Veh. [b]	3500	c	c
Rolling Resistance Coeff. (kg/kg)	0.0104	0.0098	0.0098
Frontal Area (m^2)	3.35	1.84	1.84
Aero Drag Coeff. (C_D)	0.47	0.43	0.43
Drag Area Product- C_DA (m^2)	1.57	.79	.79
Power-to-weight ratio (W/kg) [d]	12	21	17
Motor	dc	ac	dc
Peak Power (kW)	40	33.6	29.8
Maximum Speed (rpm)	6000	12,500	4500
Transmission	single-speed	two-speed	three-speed
BATTERY SPECIFICATION			
Manufacturer	Lucas Chloride (EV5T)	Sears Die Hard	ALCO 2200
Type	Tubular Lead Acid (36 x 6 V)	Lead Acid (16 x 12 V)	Lead Acid (18 x 6 V)
Weight (kg)	1134	385	545
Battery Mass Fraction	0.32	0.23	0.32
VEHICLE PERFORMANCE DATA			
Acceleration (s)			
0-48 km/h	11.6	11.2	12.5
0-80 km/h	64.8	22.0	36.4
0-88 km/h	-	28.5	47.5
Energy Consumption (Wh/km)			
48 km/h (vehicle net dc)	183	* -	-
72 km/h (vehicle net dc)	233	159	145
C-Cycle (vehicle net dc)	299	179	-
D-Cycle (vehicle net dc)	311	188	241
FUD-Cycle (vehicle net dc)	313	192	-
Range (km)			
48 km/h	182	e -	-
72 km/h	109	e -	79
C-Cycle	97	e -	-
D-Cycle	82	55.5	41
FUD-Cycle	77 [f]	e -	-
Gradeability (@ 32 km/h)	11%	18%	14%

a. Based on weighing the vehicle.
b. Assigned by developer/manufacturer.
c. Means no weight assigned because vehicle was a test bed.
d. Propulsion System Peak Power-to-weight (vehicle ratio).
e. Only minimal range data taken because of the use of marine batteries in place of EV batteries.
f. Best Effort.

TABLE S-4 INEL ELECTRIC VEHICLE TESTING SUMMARY (Cont.)

VEHICLE SPECIFICATIONS			
Vehicle Designation	Chrysler/GE ETV-1	Ford/GE ETX-I	Evcort
Weight (kg)			
Test	1723	1705	1968
Curb [a]	1522	1566	1836
Gross Veh.[b]	1822	c	c
Rolling Resistance Coeff. (kg/kg)	0.0095	0.0097	0.0136
Frontal Area (m^2)	1.84	1.78	1.90
Aero Drag Coeff. (C_D)	0.32	0.42	0.35
Drag Area Product- C_DA (m^2)	0.59	0.75	0.67
Power-to-weight ratio (W/kg)[d]	17	25	19
Motor	dc	ac	dc
Peak Power (kW)	30	43	37
Maximum Speed (rpm)	5000	9000	6000
Transmission	single-speed	two-speed	five-speed
BATTERY SPECIFICATION			
Manufacturer	JCI Phase 3 Gel/Cell	Lucas Chloride	Concorde
Type	Lead Acid (18 x 6 V)	Tubular Lead Acid (16 x 12 V)	Sealed Lead Acid (18 x 6 V)
Weight (kg)	539	520	672
Battery Mass Fraction	0.31	0.31	0.34
VEHICLE PERFORMANCE DATA			
Acceleration (s)			
0-48 km/h	10.4	07.4	8.3
0-80 km/h	23.6	21.3	25.6
0-88 km/h	28.8	29.8	32.5
Energy Consumption (Wh/km)			
48 km/h (vehicle net dc)	94	129	119
72 km/h (vehicle net dc)	108	140	144
C-Cycle (vehicle net dc)	163	201	201
D-Cycle (vehicle net dc)	154	181	-
FUD-Cycle (vehicle net dc)	174	208	212
Range (km)			
48 km/h	172	128	154
72 km/h	126	92	108
C-Cycle	85	65	79
D-Cycle	82	58	-
FUD-Cycle	75	60	72
Gradeability (@ 32 km/h)	18%	25%	17

a. Based on weighing the vehicle.

b. Assigned by developer/manufacturer.

c. Means no weight assigned because vehicle was a test bed.

d. Propulsion System Peak Power-to-weight (vehicle ratio).

e. Only minimal range data taken because of the use of marine batteries in place of EV batteries.

f. Best Effort.

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ACRONYMS AND ABBREVIATIONS

A	Amperes, Unit of Current
ac	Alternating Current
Ah	Ampere-hours
BMS	Battery Management System
DOD	Depth-of-Discharge
DOE	Department of Energy
dc	Direct Current
ETX-I	Electric Transaxle Program Test Vehicle - I
ETV-1	Electric Test Vehicle - 1
FUDS	Federal Urban Driving Cycle
I	Electric Current
INEL	Idaho National Engineering Laboratory
JCI	Johnson Controls, Inc.
JPL	Jet Propulsion Laboratory
LCEVS	Lucas Chloride Electric Vehicle System
rpm	Revolutions per minute
SAE J227 C and D	Society of Automotive Engineers J227 Driving Cycles
SFUDS	Simplified Federal Urban Driving Cycle
SOC	State-of-Charge
V	Battery Voltage in Volts
W/kg	Battery Power Density on Watts per kg

1. INTRODUCTION

This report is concerned with the test and evaluation of the ETX-I electric test vehicle, which is a Mercury LN7 retrofitted with the single-shaft AC electric powertrain developed by Ford and General Electric under contract to the U.S. Department of Energy (DOE) during the period 1982-1985. The lead-acid battery used in the ETX-I was developed by Lucas Chloride Electric Vehicle (EV) Systems (LCEVS) as part of the same DOE contract. Extensive tests of the powertrain and battery were done by General Electric and Lucas Chloride before they were integrated into the ETX-I test vehicle by Ford. The results of the component tests are given in Reference (1) in considerable detail. Ford did limited testing of the ETX-I vehicle on a chassis dynamometer to determine the energy consumption of the powertrain for several driving schedules before the vehicle was shipped to INEL for complete dynamometer testing. Ford also performed track tests with the ETX-I to determine its acceleration performance characteristics. The results of the Ford tests are given in Reference (1) compared with the program goals for powertrain energy consumption and vehicle acceleration times.

The primary objectives of the Ford, General Electric, and Lucas Chloride EV Systems testing were to determine the component and powertrain characteristics in order to assess how well they met the program goals for each component or subsystem. The vehicle tests performed by Ford were not performed to determine the performance of the test vehicle, but to determine the performance of the ETX-I propulsion system in a test bed under known operating conditions - for example, steady state when the vehicle and powertrain were warmed-up and the battery was at a specified state-of-charge. The intent of the INEL tests of the ETX-I test vehicle and the ETX-I battery pack was to determine their performance and characteristics on driving cycles and under operating conditions that pertain to electric vehicles applications and to compare the performance of the recently developed ac powertrain and tubular plate lead-acid battery to other electric drivelines under the same conditions.

2. PURPOSE AND OBJECTIVES

2.1 Battery Characterization Testing

The objective of the battery testing performed in this program was to determine the characteristics of the ETX-I battery pack as it was delivered to INEL as part of the ETX-I propulsion system. Extensive testing of modules was performed by Lucas Chloride during the development of the battery (see Reference 1, Vol II), but only limited testing of the pack (16 modules) was performed before the pack was shipped to the INEL.

Characterization testing of the battery pack is performed before the battery is used to power the test vehicle in order to determine its capacity in standardized discharges and to assess its condition relative to the rated capacity of the modules for the same standard discharges. In addition, the characterization testing includes variable power discharges and maximum power density tests that are usually not performed by battery developers.

The battery characterization test results are used in planning the vehicle dynamometer tests and assessing whether the behavior of the battery in the vehicle tests is consistent with its known capacity and discharge characteristics. The initial testing of the battery pack also permits INEL personnel to become familiar with the charging characteristics of the battery and how the battery capacity varies from cycle to cycle. Good knowledge of the battery pack charging characteristics can help to minimize the variability between repeat tests during the vehicle test program.

After the vehicle tests are completed, additional standardized tests are performed on the battery to assess its change in capacity during the vehicle tests on the dynamometer. This testing can give an early assessment of battery life and whether there are signs of problems in this area.

2.2 Vehicle Dynamometer Testing

The objectives of the dynamometer testing of the ETX-I test vehicle are to determine its performance in terms of energy consumption, range, and acceleration in standardized tests for comparision with that of other electric vehicles of recent design and to assess how well the ETX-I vehicle and its subsystems met the goals of its development program.

In the case of the ETX-I, all program goals (see Tables 1 and 2) were interpreted by Ford to be set for the powertrain and battery and not the vehicle even though the powertrain goals were expressed in terms of vehicle related quantities such as energy consumption on the FUDS driving cycle and acceleration time from 0 to 88 km/h. No vehicle range goals were set for the ETX-I program. As will be discussed in a later section of the report, the convolution of the powertrain and battery goals in terms of vehicle parameters affected the type of testing done by Ford and the manner in which the Ford test results compare with those obtained at INEL.

Table 1. ETX-I PROPULSION SYSTEM GOALS

Program Objectives for an Escort-Size Vehicle (Reference 1)

Energy Consumption at the Battery Terminals averaged over FUDS	0.16 kWh/km (0.25 kWh/mi)
Top Speed	96 km/h (60 mph)
Acceleration time, 0 to 80 km/h (0 to 50 mph)	20 s
Gradeability	30% (@ 32 km/h)
Driveability	Automotive Industry Acceptable

Table 2. ETX-I BATTERY GOALS AND SPECIFICATIONS

Final Design Specifications (Reference 1)

Voltage	204 V rated
Energy 0 to 100 % DOD (C/3)	18 to 22 kWh
Power at 80% DOD (20 s)*	40 to 45 kW @ 133 V
Power (sustained)	25 kW
Weight	550 kg maximum
Energy efficiency - C/3	60 to 70%
Volume	10 ft^3 maximum
Charging time	8 h
Ambient temperature	-20 to 40^{o} C
Maintenance interval	3 months (excluding watering)
Vibration	Withstand over the road stress
State of charge indication	$\pm$10%
Life	800 to 1000 cycles or 3 minimum when discharged at C/3 to at least 80% DOD and recharged once in 24 h

* Subsequently amended to 40 kW @ 133 V averaged over the final 10 s of a 20 s discharge.

3. VEHICLE/POWERTRAIN DESCRIPTION

3.1 Vehicle Description

The ETX-I test vehicle is a production Mercury LN7 with the front-wheel drive transaxle-engine assembly replaced by the single-shaft, integrated ac electric powertrain. The lead-acid battery in the ETX-I is placed behind the front seat in the rear seat area. A schematic drawing of the ETX-I is shown in Figure 1 taken from Reference 1. Note that the ETX-I vehicle is a test bed for the ETX-I AC powertrain and no attempt was made by Ford to place the batteries such that they did not reduce the passenger capacity of the LN7 from four to two. The characteristics of the ETX-I test vehicle are given in Table 3. A vehicle test weight of 1705 kg was used in the INEL tests compared to 1590 kg used by Ford. The INEL test weight is based on weighing the vehicle prior to the coastdown tests.

3.2 Powertrain Description

A block diagram of the ETX-I powertrain is shown in Figure 2 taken from Reference 1. The various components in the propulsion system and the ways in which they are interconnected are indicated in the figure. The most distinctive characteristic of the ETX-I powertrain is that the traction motor and automatic two-speed transmission are mounted on a single-shaft, in the same enclosure with a common cooling system. This assembly (Figure 3) is referred to as the transaxle in Figure 2.

Table 3. ETX-I TEST VEHICLE CHARACTERISTICS

Test weight (kg)	1705
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Drag Coefficient	0.42
Projected Frontal Area (m^2)	1.775
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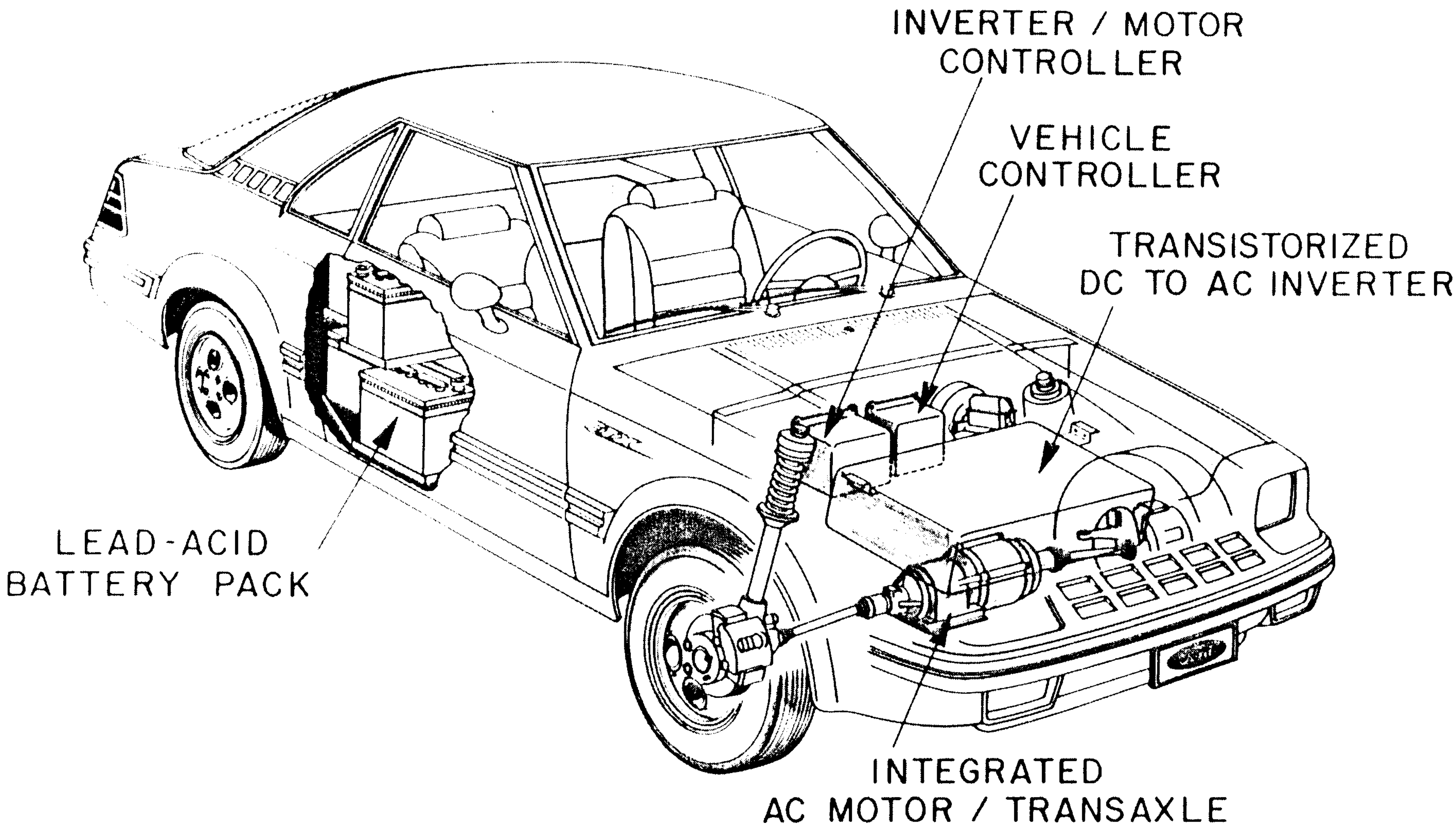


9-0102

Figure 1. Schematic drawing of the ETX-I test vehicle.

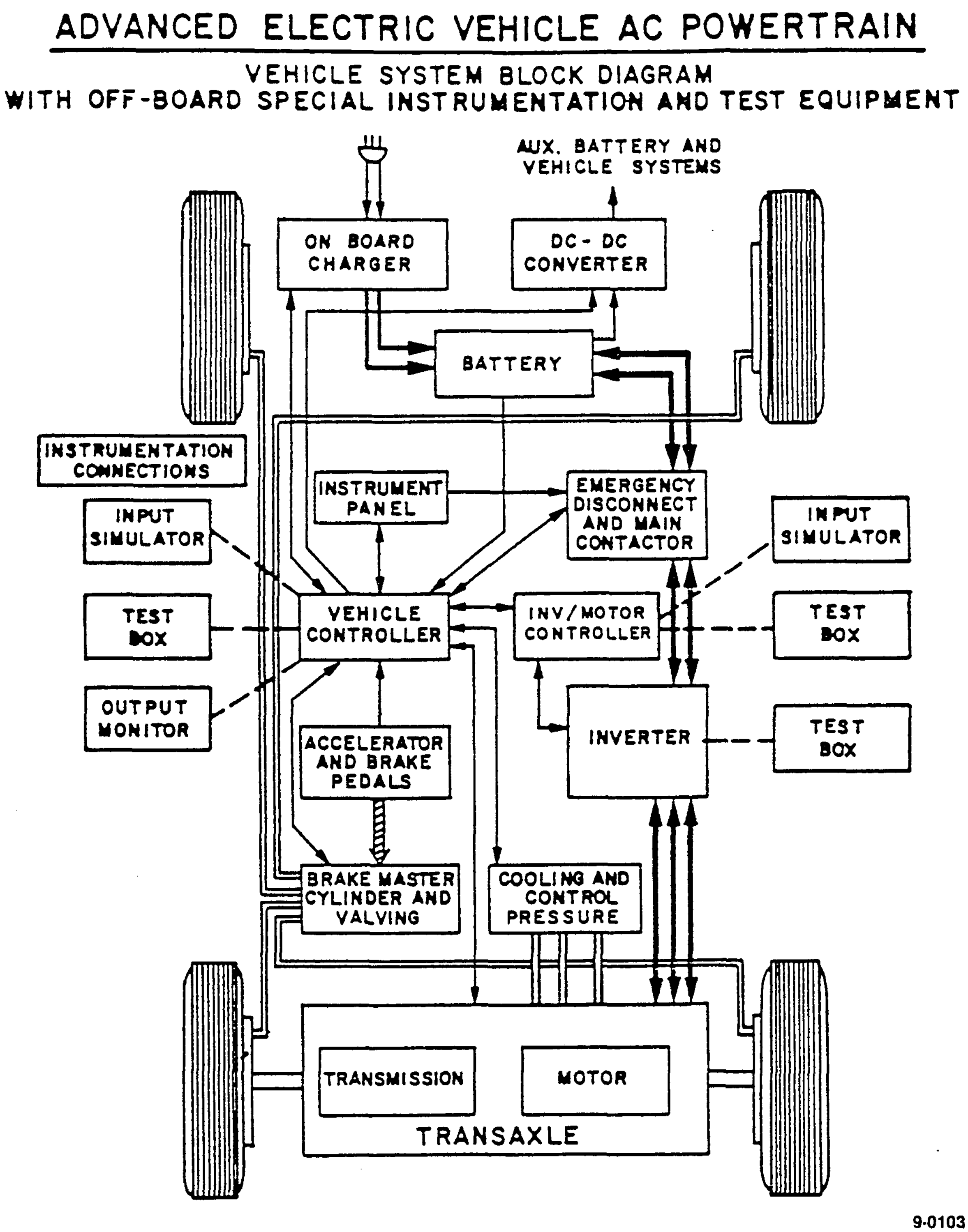
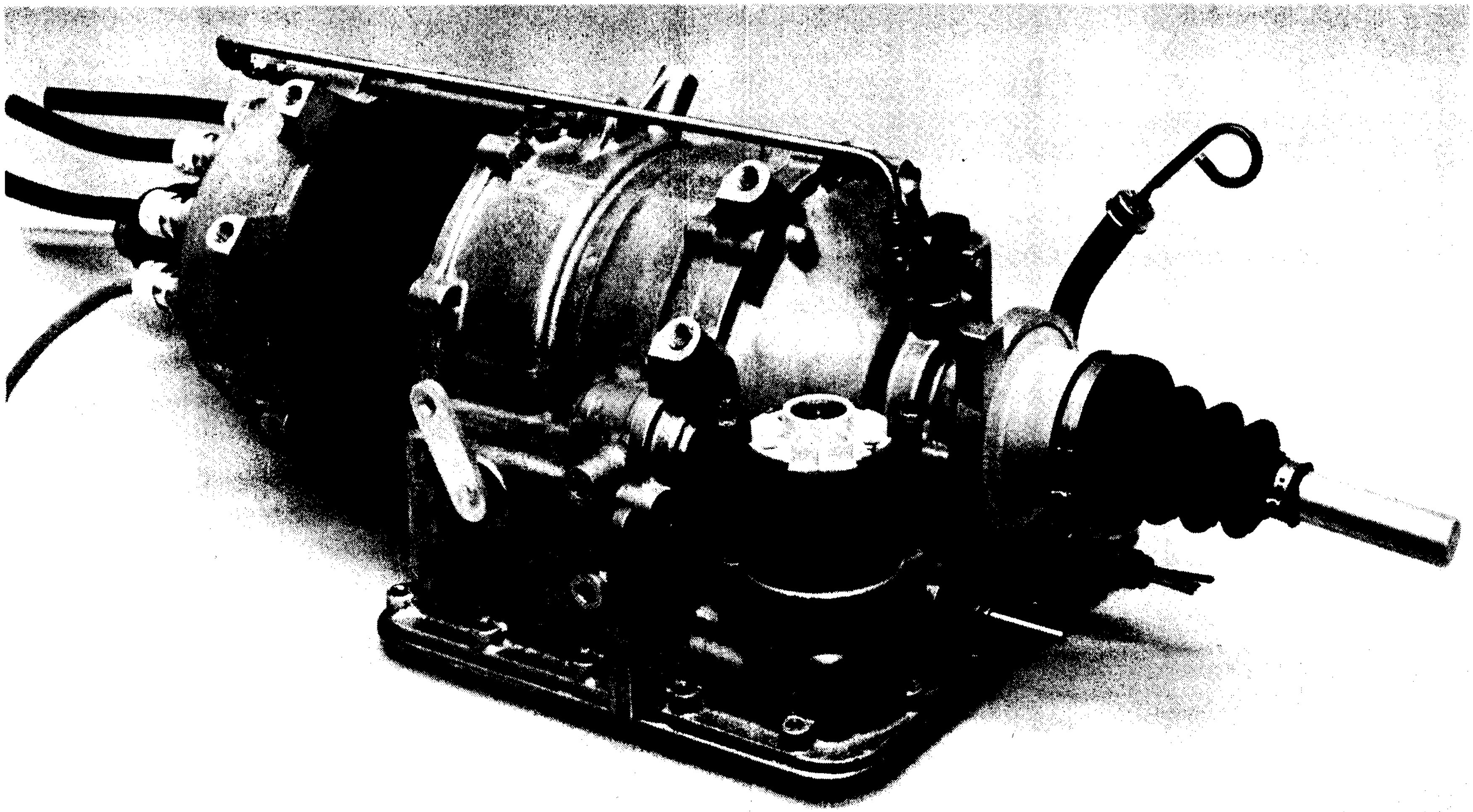


Figure 2. Block diagram of the ETX-I AC propulsion system.



9-0104

Figure 3. Photograph of the motor/transaxle assembly.

The integrated design results in a much smaller and lighter package than is possible with other approaches and is one of the prime reasons why the performance of the ETX-I vehicle is of special interest.

The component specifications for the powertrain are given in Table 4. Detailed descriptions of the complete powertrain and the individual components are given in Reference 1, Vol. I. Each of the components are discussed briefly in the following sections.

TRACTION MOTOR

The electric motor is an oil cooled, three-phase ac induction motor mounted inside the transaxle concentrically on the drive shaft axis. The motor is a two-pole design with a 0.12-m stack length and a 0.22-m outer diameter stator. The weight of the motor is 42.5 kg (93.8 lb). The maximum torque of the motor is 95 N-m (70 ft-lb) with the corner point of the motor at approximately 3800 rpm. The maximum motor output power at 153V is 34.5 kW (46 hp) at about 5000 rpm. The maximum motor power decreases with speed until it is 28.5 kW (38 hp) at 9000rpm. The ac motor is pulse width modulated (PWM) at speeds below the corner point and square wave moduled at higher speeds.

INVERTER/MOTOR CONTROLLER

The inverter is the high power electronic interface between the ac traction motor and the battery, which converts the dc battery current to three phase quasi-sinusoidal current having the frequency and amplitude required by the ac motor. The motor controller translates the torque commands from the microcomputer based vehicle controller to inputs to the inverter transistor base drives that turn on/off the power Darlington transistors that control the motor current. The inverter/motor controller contains two Intel 8751 microcomputers plus analog and digital circuitry. The power transistor circuits are designed to meet instanteous voltage and current peaks of 400 V and 400 A, respectively. The complete inverter package weighs 40 kg (88 lb) and has a volume of 0.05-m^3 (1.7 ft^3). The controller operates the inverter to provide closed-loop control of the motor torque for both motoring and regeneration. During motoring, the power is limited so that the battery voltage never falls below 134 V.

Table 4. ETX-I POWERTRAIN CHARACTERISTICS

Motor	
Type	Three-phase ac induction
Peak Power (kW)	43 at 185 V, 34 at 153 V
Maximum Speed (rpm)	9000
Maximum torque (N-m)	95
Control method	Sinusoidal Current
Developer	General Electric Co.
Transmission	
Type	Two-speed automatic
Gear Ratios	
First	15.52
Second	10.15
Developer	Ford Motor Co.
Battery	
Type	Tubular Lead-acid
Weight (kg)	
Modules (16*12 V)	520
System	634
Voltage (Nominal)	192
Capacity	
Ah at C/3	98
kWh at C/3	18
Developer	Lucas Chloride

TRANSAXLE

As noted previously the transaxle assembly includes both the ac traction motor and an automatic, two-speed transmission, which are mounted on the same shaft. The output of the motor is input to the transmission by a sun gear that is cut into the motor rotor shaft. The transmission gear train,including the final drive ratio, consists of two planetary gear sets that are active full-time. In first gear, the overall ratio is 15.52:1. In second gear, the ratio is 10.15:1 resulting in a 1.53 gear step ratio across the transmission. Shift control is electronically controlled by the vehicle microcomputer. The shift from first gear to second requires no timing and is accomplished by applying the second gear clutch. The transaxle assembly weighs 87.2 kg (192 lb). This includes 42.5 kg for the motor, 32.6 kg (72 lb) for the transmission, and 12 kg (26.5 lb) for axle shafts and joints.

TUBULAR LEAD-ACID BATTERY(Lucas Chloride)

The lead-acid battery, which powers the ETX-I vehicle, uses thin tubular-plate positive and flat-plate negative electrodes (see Figure 4). This design is intended to attain the high power density of thin electrodes and separators and the long life of tubular positive plates. The ETX-I battery pack consists of 16, 12 v modules with a nominal pack voltage of about 200 V. The average module weight is 32.5 kg (71.5 lb), resulting in a pack battery weight of 520 kg (1144 lb). The module dimensions are width-159 mm, length-400 mm, height-230mm. The battery pack volume is then 0.234 m^3 (8.25 ft^3).

Considerable test data taken by Lucas Chloride is given in Reference 1, Vol. II for the ETX-I modules. The data indicate a module energy density of 35.8 Wh/kg at the 3 h discharge rate and 32.5 Wh/kg at the 2hr rate. Pulse tests of the modules showed a module voltage of 10 V for current of 310 A at 0% depth of discharge. This corresponds to a module power density of 78 W/kg and a power from the pack of 50 kW.

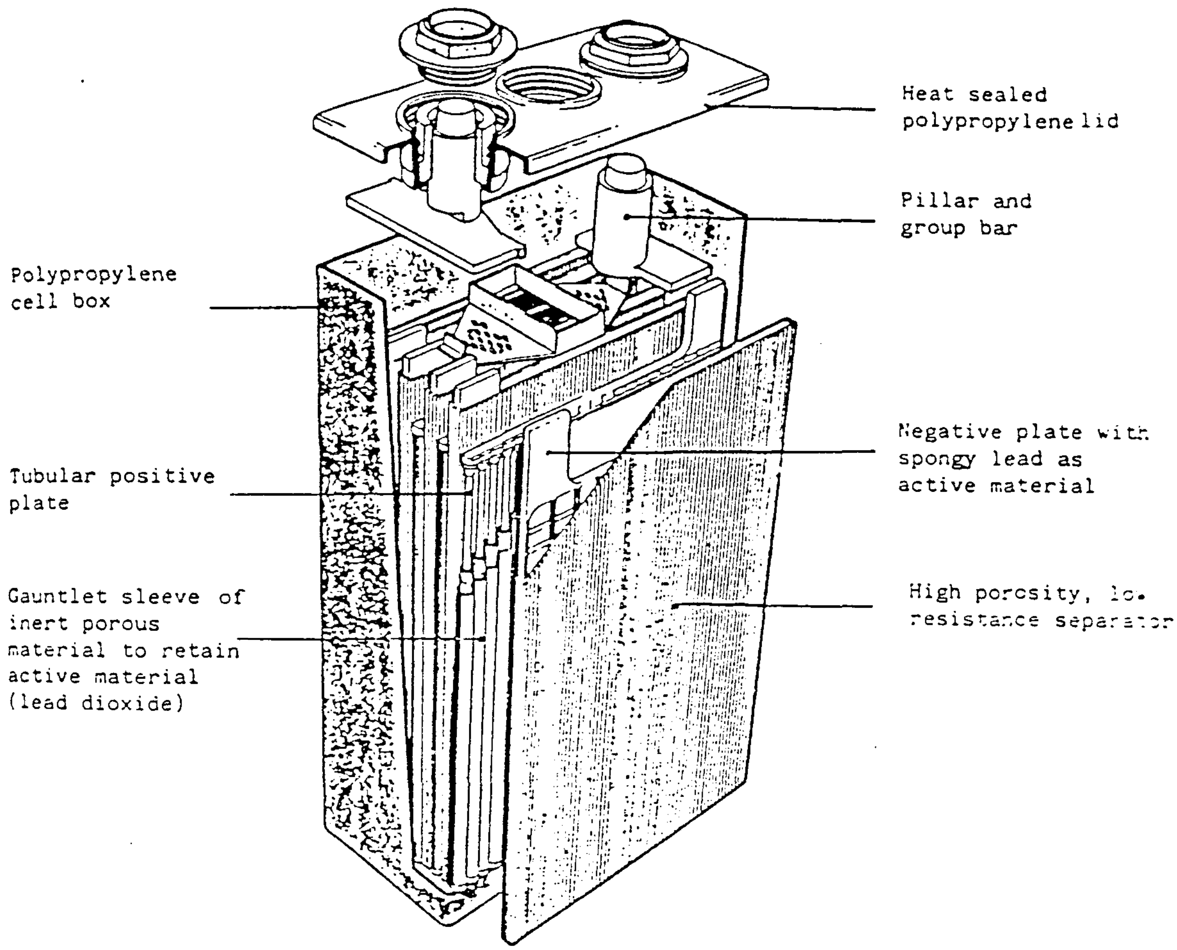


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Figure 4. Schematic drawing of the ETX-I tubular plate battery.

BATTERY MANAGEMENT SYSTEM

Lucas Chloride developed a battery management system (BMS) for the ETX-I battery that supervises the charging of the traction and auxilary batteries and determines the SOC and capacity of the traction battery during discharge. The ETX-I battery is forced air-cooled, but battery temperature is under the control of the vehicle microcomputer and not the battery management system. A photograph of the complete battery and its support systems is shown in Figures 5(a) and 5(b). The on-board weight of the battery management system, including the container, is 634 kg (1395 lb).

The battery management system (BMS) consists of a logic unit employing a Motorola 6803 microprocessor chip, a power supply unit, which interfaces with the traction battery, and an on-board battery charger. Battery temperature, voltage, and current are measured on a regular basis by the BMS and used as inputs to its software to determine battery SOC during both charge and discharge modes of operation. The BMS regulates the battery charging current based on battery voltage and its change with time to avoid overcharging and undercharging the battery.

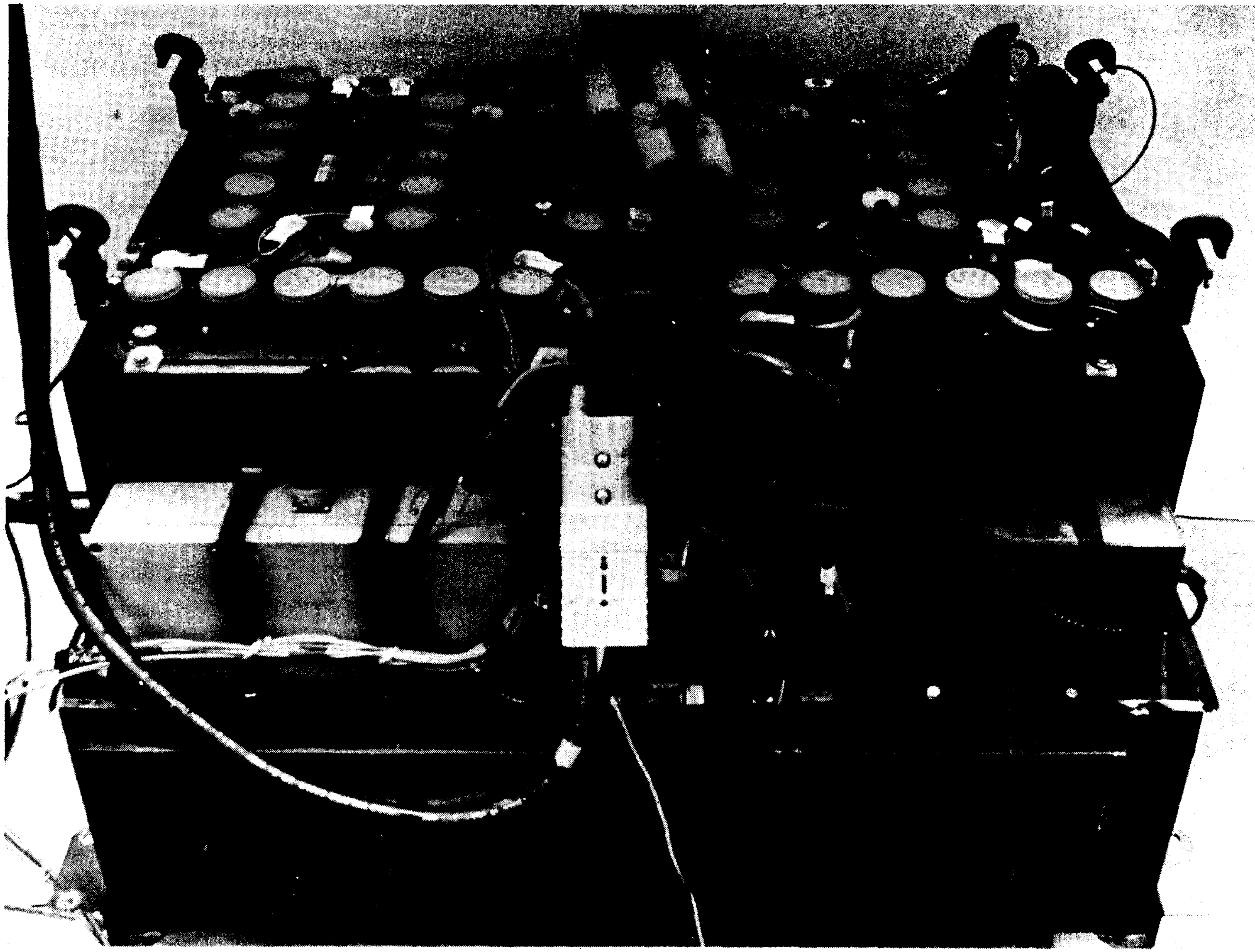

Figure 5a. Photograph of ETX-I battery.

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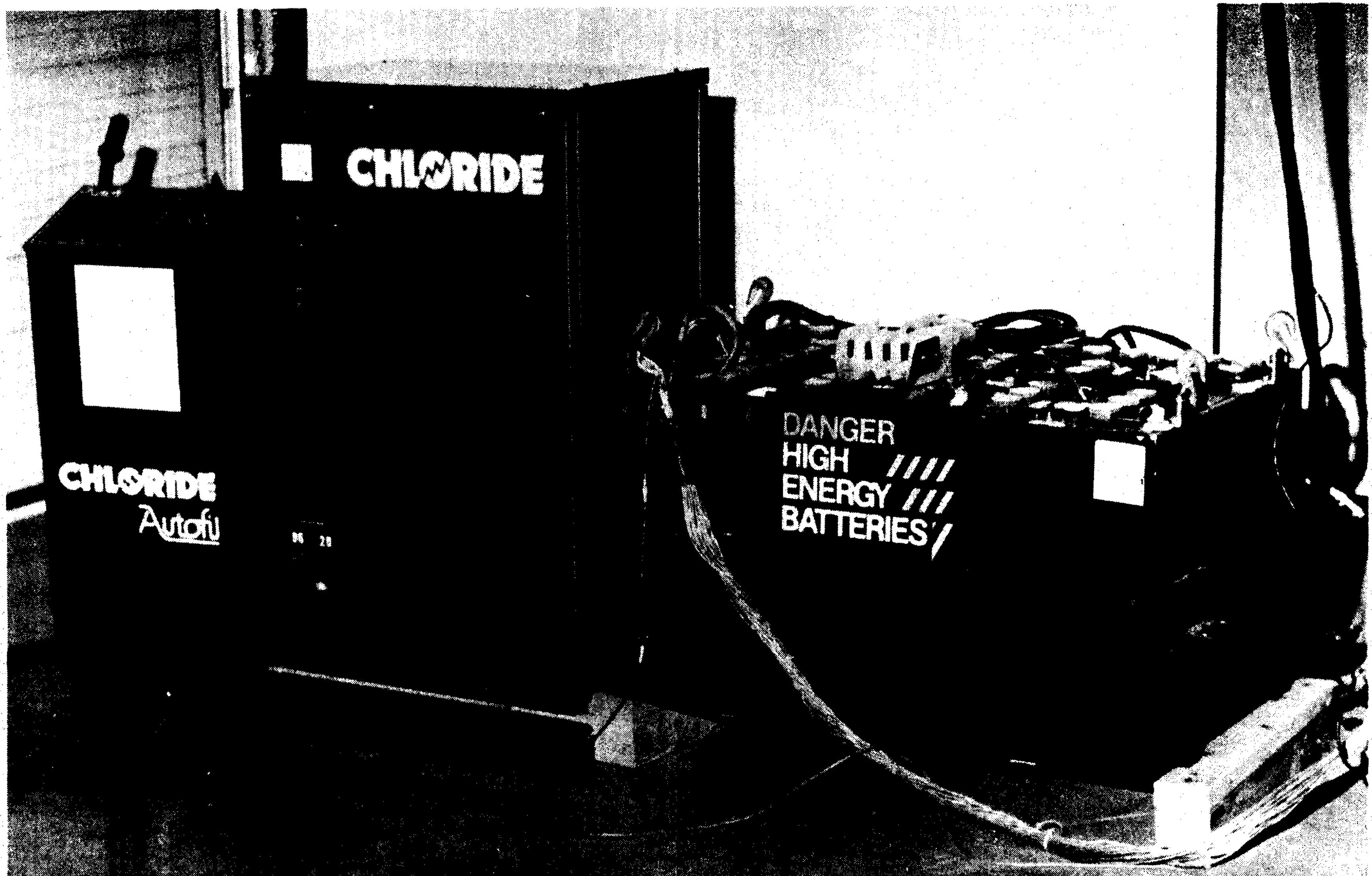

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Figure 5b. Photograph of ETX-I battery and support systems.

4. TEST EQUIPMENT, INSTRUMENTATION, AND PROCEDURES

4.1 Battery Characterization Tests

The battery characterization tests were performed in the INEL Battery Laboratory. They consisted of constant current, constant power, and variable power discharges of the battery and a series of 30 s peak power pulses from the battery at selected states-of-charge during c/3 discharges. After each discharge, the battery was charged following the battery manufacturer's specifications.

The INEL Battery Laboratory consists of multiple workstations including a Normalizer, a Load Bank, and a Simulator (see Figure 6). Each station can be controlled manually from a front panel or externally through an IBM PC. The Normalizer that is used to provide constant current and constant power discharges of batteries operates over the following ranges:

Discharge voltage	3 to 220 Vdc
Discharge current	10 to 400 A
Charge current	0 to 50 A
Charge voltage	3 to 300 Vdc

The Normalizer provides high battery currents and voltages over a long time period (minutes to hours) but has a relatively slow response time.

The Load Bank, which is used in the pulsed, peak power tests of the battery is able to provide the following range of discharge conditions:

Voltage:	3 to 34 Vdc
Current:	10 to 1000 A

The Load Bank can provide the high current pulses and has an extremely fast response time of less than 1 s.

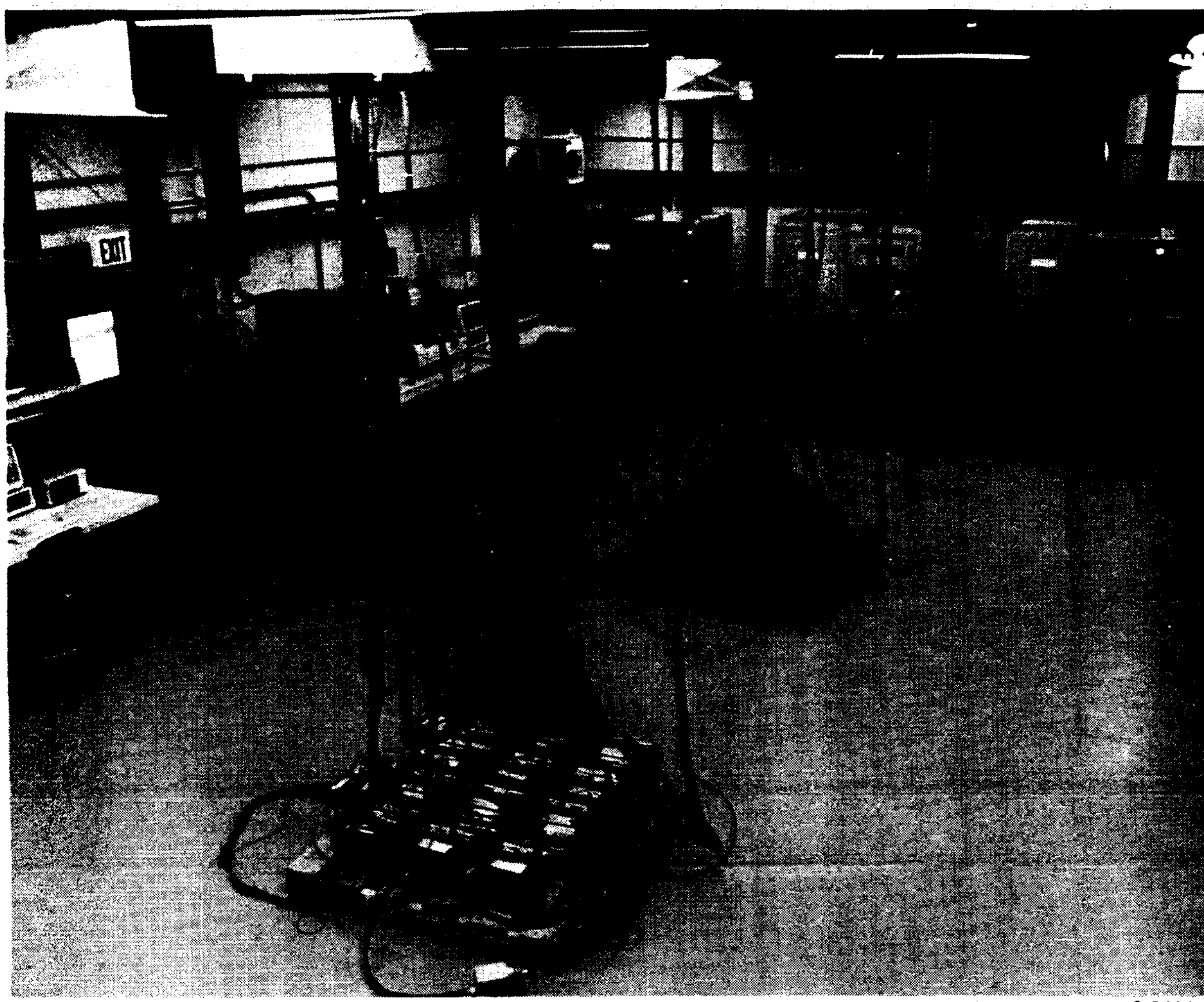

Figure 6. Photograph of the INEL battery test laboratory.

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The Simulator can be programmed to perform variable power discharges consisting of repeated complex power profiles such as would be experienced by the battery in a vehicle on the FUDS or SFUDS driving schedule.

The simulator can provide conditions in the following ranges:

Charge voltage:	3 to 300 Vdc
Charge current:	1 to 150 A
Discharge voltage:	3 to 220 Vdc
Discharge current:	10 to 400 A

The Simulator, which has a fast response time of 1 s, is used to perform the variable power discharges.

Battery charging is done using the Normalizer or a Hewlett Packard power supply (Model HP-64776) with a charge controller built by the EG&G Idaho Electronics group. The chargers can handle complex charging algorithms with constant current and taper steps.

Each of the three workstations is controlled by a separate IBM PC XT, which performs data acquisitions, retrieval, reduction, and analysis functions. The workstations are linked to the Normalizer, Load Bank, and Simulator by Neff 470 NDAS data acquisition hardware and software. The Neff 470 permits measurements of pack voltage and current and module voltages and temperatures. The NDAS system is menu driven on the PC for both data acquisition and playback modes. Sampling times of 1 s are used in most discharge tests, but sampling times as short as 0.1 s are used for the peak power test.

All battery characterization testing is performed in accordance with Electric & Hybrid Vehicle Program Test Procedures, ETV-BAT-984. The procedure for each type of test is given in detail in that reference.

4.2 Vehicle Dynamometer Testing

4.2.1 Test Equipment and Instrumentation

Dynamometer tests of the ETX-I test vehicle were performed in the INEL Electric Vehicle Dynamometer Laboratory. A photograph of the laboratory with the ETX-I on the dynamometer is shown in Figure 7. The key components of the laboratory are an electromechanical Clayton chassis dynamometer and a computer-automated data acquisition system (DAS). The DAS is a Standard Engineering Corporation MIK-11/73 microcomputer with a Digital Equipment Corporation (DEC) LSI-11/73 processor-board housed in a CAMAC crate. The CAMAC provides a flexible system to handle a wide variety of input/output hardware. Details of the data acquisition system and related hardware are given in References 2 and 3. The instrumentation used in the Electric Vehicle Dynamometer Laboratory is listed in Appendix A.

The test vehicle, battery pack, and dynamometer were instrumented so that the following quantities could be recorded by the DAS:

1. Motor phase current
2. Motor phase voltage
3. Motor field current
4. Battery current
5. Battery voltage
6. Battery power
7. Battery temperatures
8. Dynamometer rpm (rolls)
9. Dynamometer torque
10. Motor temperature
11. Transaxle temperature
12. Accessory battery voltage
13. Accessory battery current
14. Vehicle half-shaft RPM
15. Vehicle half-shaft torques

The data can be recorded at either 0.1 or 1.0 s time increments. Second-by-second printouts of each of the measured variables can be obtained after the test from the DAS. Plots of the data versus time can also easily be obtained.

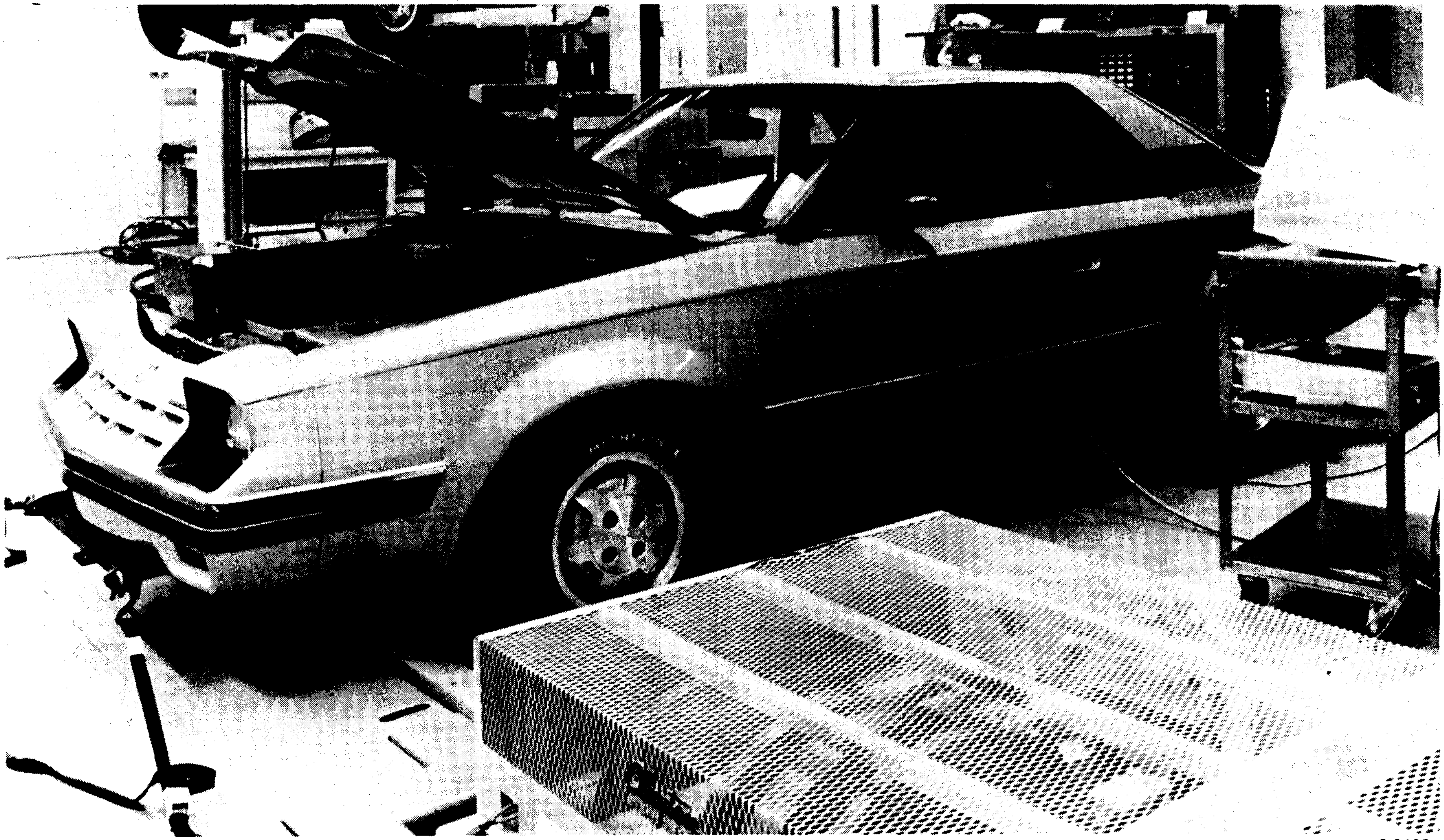

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Figure 7. Photograph of the ETX-I test vehicle in the INEL vehicle dynamometer laboratory.

4.2.2 Dynamometer Setup Procedures

The procedure for setting up the dynamometer for testing electric vehicles at INEL is well established based on past work on a number of vehicles. It involves obtaining good track coastdown data for the vehicle being tested and matching the dynamometer coastdown curve with that measured on the track.

Track coastdown tests of the ETX-I test vehicle were run by INEL in April and May of 1987 at the Chrysler Proving Grounds in Phoenix, Arizona. Twenty-four coastdowns were performed (12 in each direction). The data were corrected for weather conditions using information obtained from an on-site weather station. The coastdown tests were run in the early morning hours while the wind speed was below 4.8 km/h. The coastdown data were reduced and normalized to standard atmospheric conditions using an analytical technique developed at INEL (see Reference 4). The average vehicle parameters obtained from the track coastdown tests are:

Test weight	1705 kg
Tire rolling radius	0.289 m
Aerodynamic drag coefficient	0.416
Frontal area (projected)	1.77 m^2
Rolling Resistance Coefficients	
C0	0.0097
C1	0.0

The procedure used to match the road load of the vehicle on the dynamometer with that on the track is given in detail in Appendix B. This is done by matching a computer generated coastdown curve based on the track coastdown tests with the vehicle coastdown curve on the dynamometer. The INEL dynamometer is equipped with a programmable microprocessor controller through which the road load is changed by varying the input values of drag area product (CD A) and the rolling resistance coefficients (C0, C1) for the vehicle being tested. The CD A and rolling resistance values are varied until the dynamometer and target coastdown curves agree to the desired accuracy.

The coastdown curve used for the ETX-I test vehicle is shown in Figure 8. A comparison of the track and dynamometer coastdown times are is given in the table below. Also shown are the coastdown times for the ETX-I on the dynamometer at Ford.

INEL Dyno		Track Coastdown		Ford Dyno	
Velocity (km/h)	Time (s)	Velocity (km/h)	Time (s)	Velocity (km/h)	Time (s)
88 to 72	20.61	88 to 72	20.61	88 to 72	20.37
32 to 16	42.63	32 to 16	42.67	32 to 16	44.0
96 to 16	148.22	96 to 16	149.16	---	---

The agreement between the coastdown times in the various tests is quite close indicating a good match between the road loads for the ETX-I test vehicle on the track and on the dynamometers.

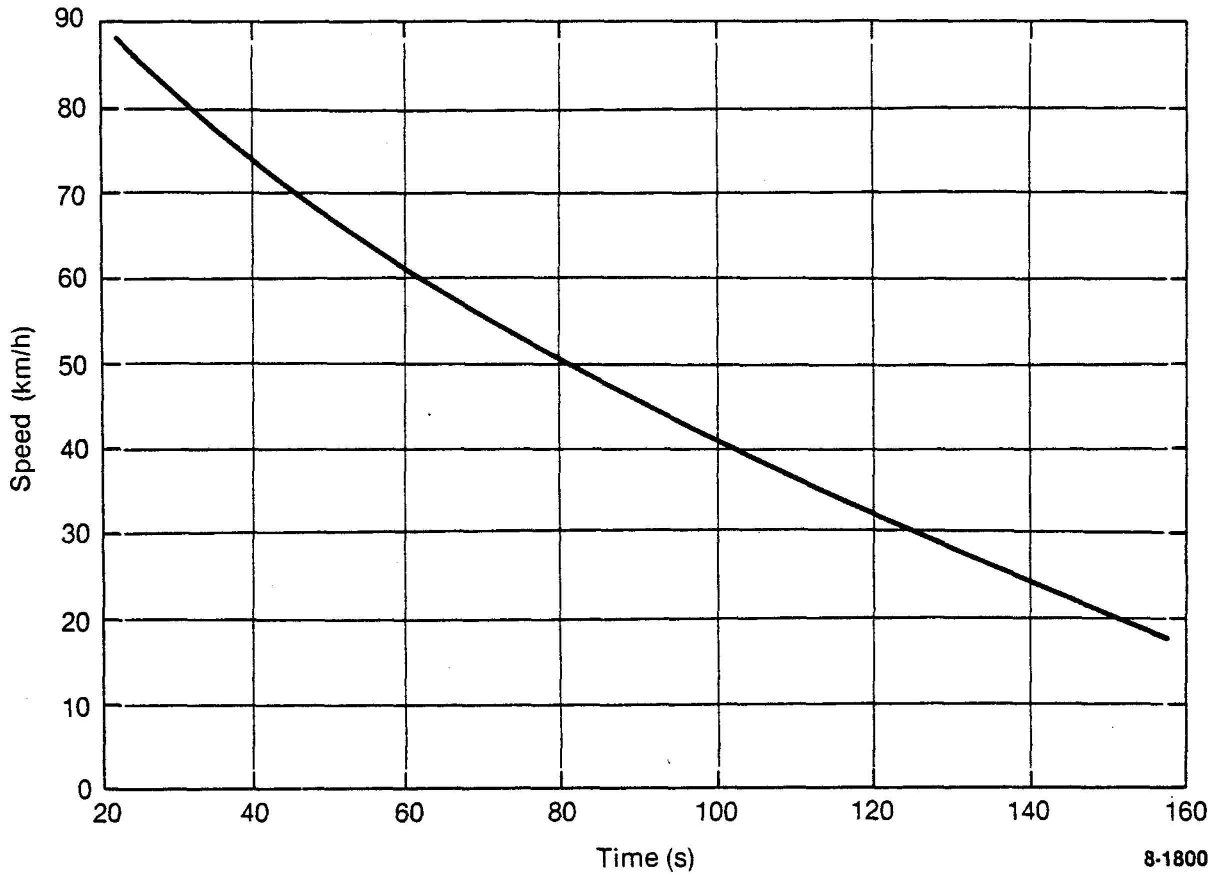

Figure 8.ETX-I dynamometer coastdown curve.

5. BATTERY CHARACTERIZATION

A series of tests on the ETX-I battery were performed in the INEL Battery Test Laboratory before and after the battery was tested with the vehicle in the INEL Vehicle Dynamometer Laboratory. The results of those tests are discussed in this section of the report and, where appropriate, compared with similar data from the Lucas Chloride and Ford tests of the battery. A Summary Data Table for the INEL tests of the ETX-I battery in both the Battery and Electric Vehicle Dynamometer Laboratories is given in Appendix C. A total of 145 charge/discharge cycles were run on the battery at INEL. The first forty-eight (48) cycles on the battery were done at Ford before it was shipped to INEL. The ETX-I battery had experienced a total of 193 cycles by the end of the test program at INEL.

Twenty-four (24) pretest characterization cycles and the 19 posttest characterization cycles were run in the Battery Laboratory before and after the vehicle dynamometer tests. Seventy-five cycles occurred during the dynamometer testing of the ETX-I test vehicle. An additional 15 cycles were run in the Battery Laboratory during a break in dynamometer testing to check the battery capacity that was thought to be decreasing.

5.1 Constant Current Discharges

Constant current discharge tests of the battery were performed at 32, 45, and 74 A. The results (Ah versus I) are shown in Figure 9 for both the pre and the posttests of the battery. Also shown in Figure 9 are the capacity data of Lucas Chloride taken from Reference 1, Vol. II.

The pretest pack capacity measured at INEL was about 9% less than reported by Lucas Chloride based on module data. The posttests indicated the pack capacity decreased 10 to 15% during the vehicle dynamometer testing.

5.2 Constant Power Discharges

Constant power discharge tests of the battery were performed at power densities of approximately 8, 25, and 50 w/kg, based on module weight. The cut-off voltages used in the constant power tests are given in the table below.

Power Density (W/kg)	Cut-off Voltage (V/cell)
8	1.6875
25	1.573
50	1.4375

The constant power discharge data were used to plot the Ragone curve (Energy density versus Power density) shown in Figure 10. Both the power and energy density are based on module weight only excluding the weight of the battery box and battery management system. Constant power discharge data from Lucas Chloride are not available from Reference 1, Vol. II for comparison with the INEL results. Note in Figure 10 the shift in the Ragone curve from pre to posttest indicating a decrease in battery capacity.

5.3 Peak Power Tests

Peak power tests were performed with the ETX-I battery. In those tests, a module is discharged at the 3 h rate (about 32 A in this case). After withdrawing Ah corresponding to 0%, 50% and 80% depth-of-discharge, the module is subjected to a 30 s, high current pulse. Prior tests are performed to determine the current for each depth-of-discharge that yields a voltage equal to 2/3 of the open-circuit voltage of the module for the first several seconds of the discharge. For a lead-acid battery, the open-circuit voltage is 2.1 V/cell so that the voltage near the beginning of the high current pulses should be 1.4 V/cell. The pulse currents for the peak tests of the ETX-I battery were 539, 450, 422 A for 0%, 50%, 80% DOD, respectively.

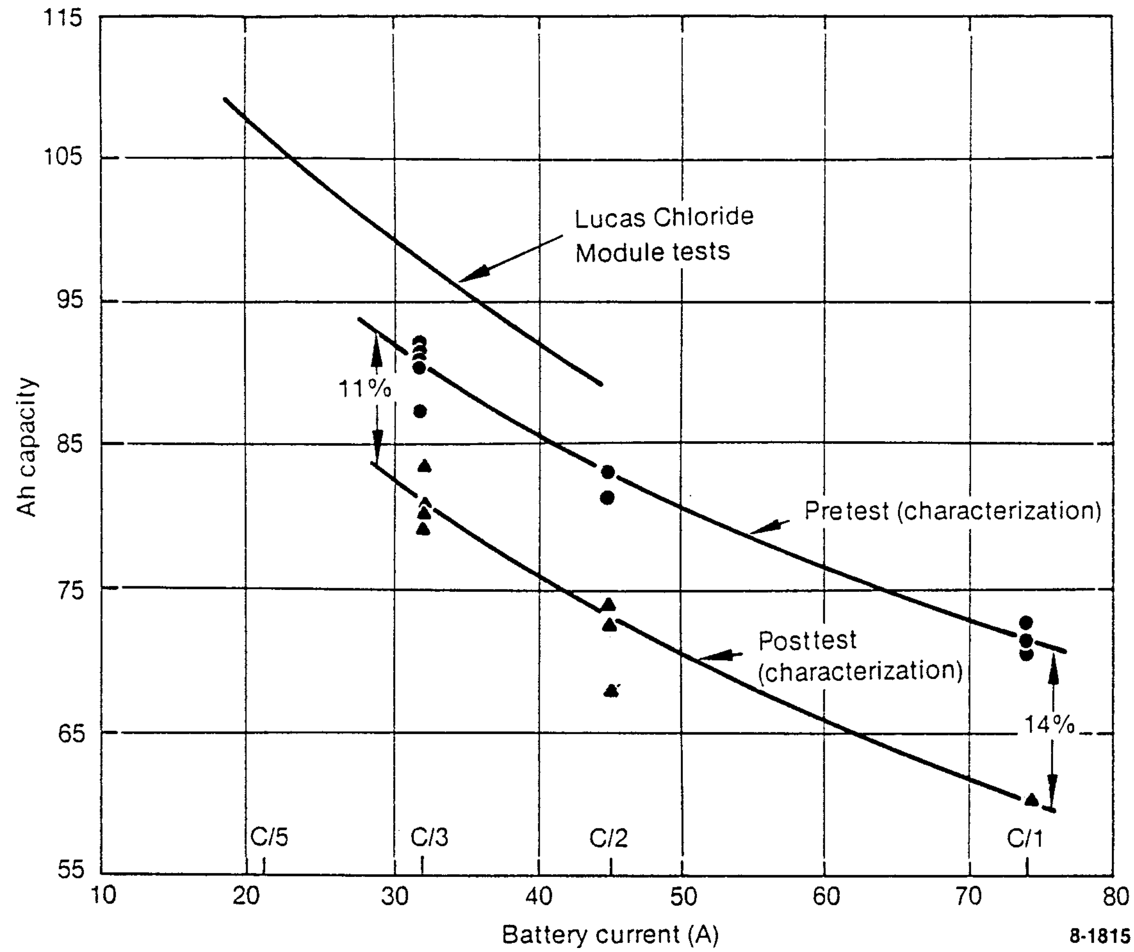

Figure 9. Peukert curve for the ETX-I battery.

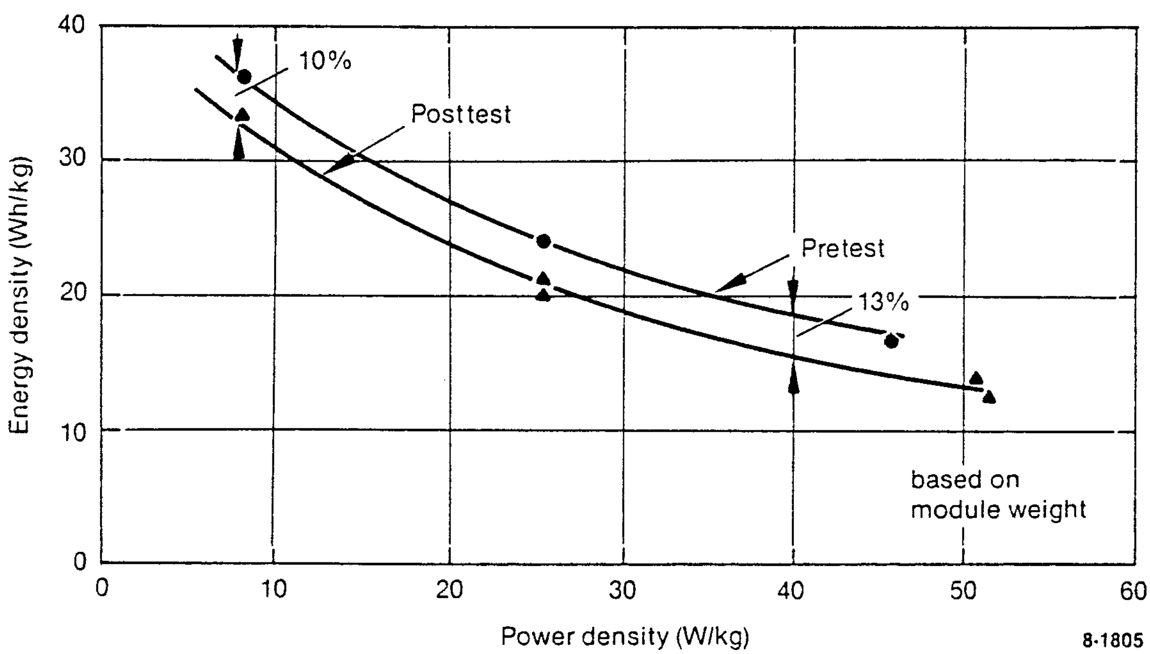

Figure 10. Ragone curve for the ETX-I battery.

The results of the peak power tests averaged for several modules are given in Figures 11 and 12. Figure 11 shows the module voltage as a function of discharge time for the peak power discharges at the three depths-of-discharge. A large voltage droop with time at the high depth-of-discharge is clearly evident in Figure 11.

The power density as a function of time for the peak power discharges is shown in Figure 12. The data indicate that the power density of the ETX-I battery decreases significantly with increasing depth-of-discharge especially for DOD greater than 50%. When the voltage decreases rapidly with time after the high current is applied, as in the case of DOD = 80% in Figure 12, the useable peak battery power density is sensitive to the minimum voltage requirement of the vehicle motor/controller. This is the case for the ETX-I vehicle which requires a minimum battery voltage of 134 V (1.4 V/cell). Based on the INEL peak power tests, it is reasonable to expect that the ETX-I battery can supply in excess of 55 kW, if needed, at DOD <50%; at higher DOD the maximum power capability is significantly less and more dependent on the time period for which high power is demanded by the vehicle.

Lucas Chloride did considerable pulse discharge testing (see Reference 1, vol. II) of the ETX-I modules. Tests were performed in which 20-s pulses at selected currents were withdrawn from the battery at 0%, 50%, and 80% depths-of-discharge during a 3h constant current discharge. The pulse currents were 120, 170, 220, 250, 280, 310 A. As shown in Figure 13, an extrapolation of the Lucas Chloride data is consistent with the INEL peak power data that were taken at the same 3 hr discharge rate, but at higher pulse currents. The good agreement between the two sets of pulse discharge data after 10 s indicate that the pulse characteristics of the battery as delivered to INEL were essentially the same as those measured by Lucas Chloride soon after its manufacture.

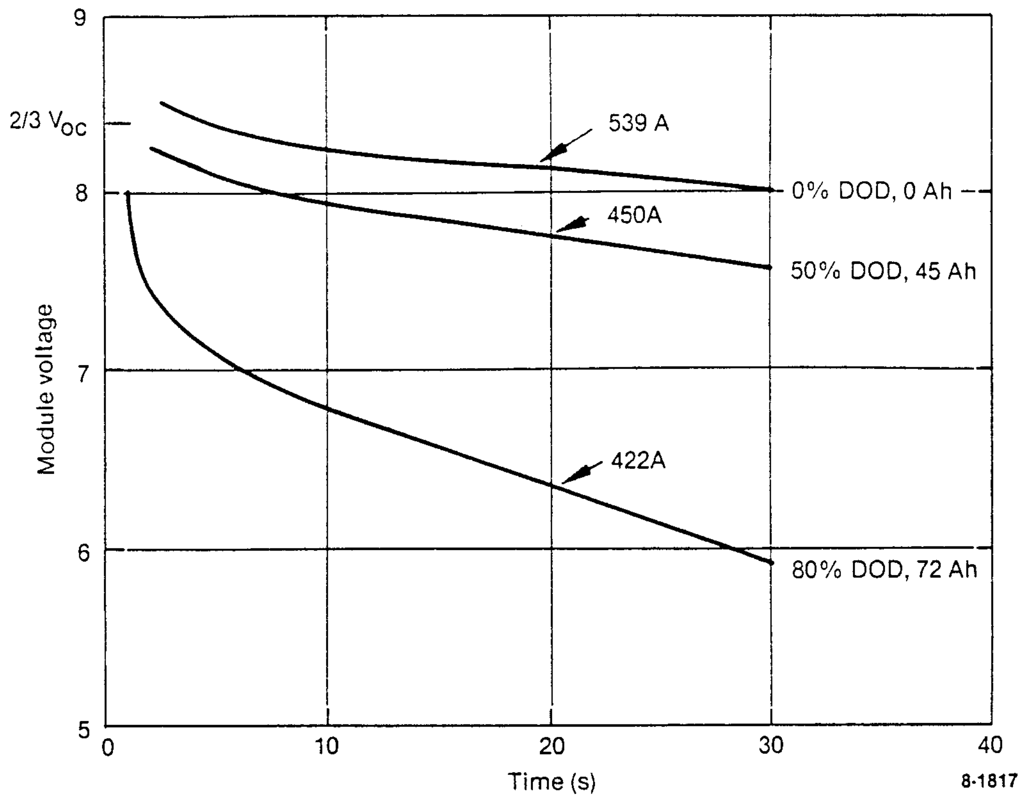

Figure 11. Voltage vs. time for the peak power tests.

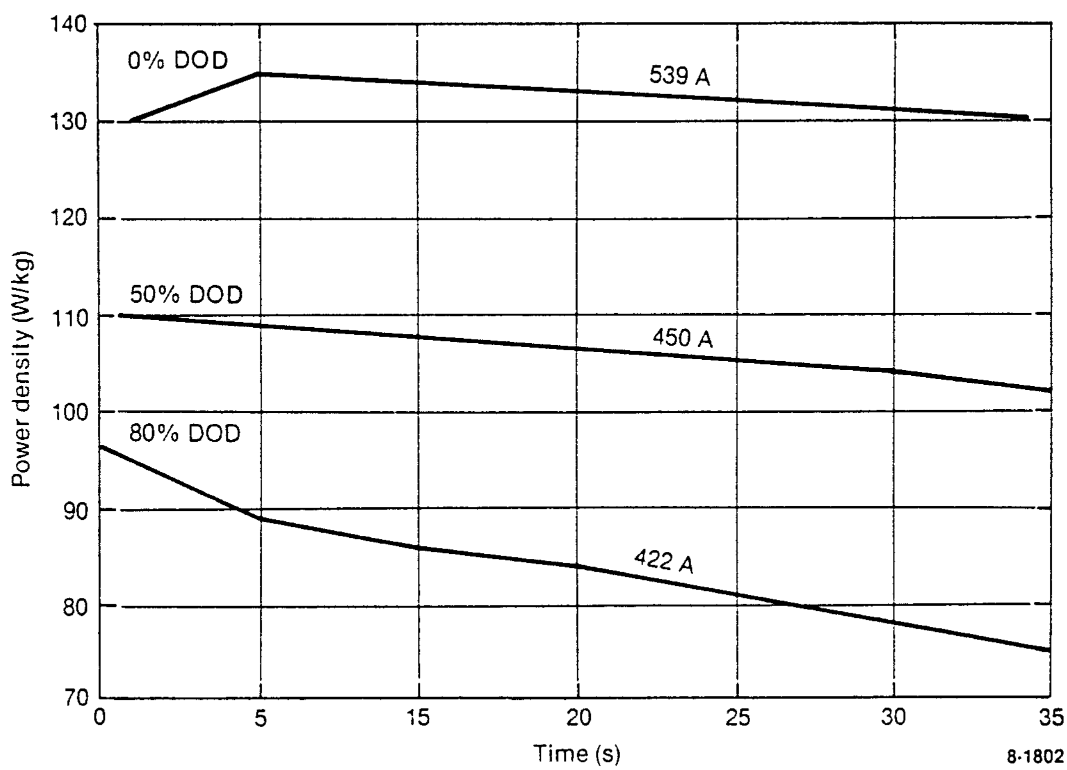

Figure 12. Power density vs. time for the peak power tests.

5.4 Variable Power Discharges

The response of the battery in an electric vehicle is most directly described in terms of battery voltage (V), current (I), and depth-of-discharge (DOD). In urban driving, the battery current and power vary rapidly with time as the vehicle accelerates and decelerates with the average discharge current being much less than the peak current. In order to determine the battery response for this type of discharge, data from variable power tests are required.

Data from constant power discharge tests are of limited value because the pulse peak power is much greater than the battery can sustain for long periods of time. The most directly applicable battery data are that obtained from SFUDS tests of the battery in the Battery Laboratory or from dynamometer tests of the vehicle powered by the battery on the FUDS driving cycle. The voltage-current-DOD characteristics for the ETX-I battery based on SFUDS and FUDS data are shown Figures 14 and 15. Battery response during pulsed, variable power discharge can also be obtained from the Lucas Chloride pulse tests, which were discussed in the previous section. Those results were given in Figure 13.

The battery capacity (Ah or kWh) for a particular test depends on the average discharge current and discharge profile, as well as the termination criteria used in the test. For nearly equivalent discharges the measured capacity of the battery can differ significantly if different test termination criteria are used. This was the case for the SFUDS and FUDS tests at INEL.

The capacity of the battery in the SFUDS test in the Battery Laboratory was only 43.5 Ah, because the test was terminated when the battery voltage dropped below 1.4 V/cell during the peak power (79 W/kg) portion of the SFUDS test cycle. The battery capacity for the FUDS cycle on the dynamometer was 70.5 Ah with the test being terminated when the ETX-I vehicle could no longer approximately follow the FUDS driving cycle with the battery voltage remaining above 134 V (1.4 V/cell).

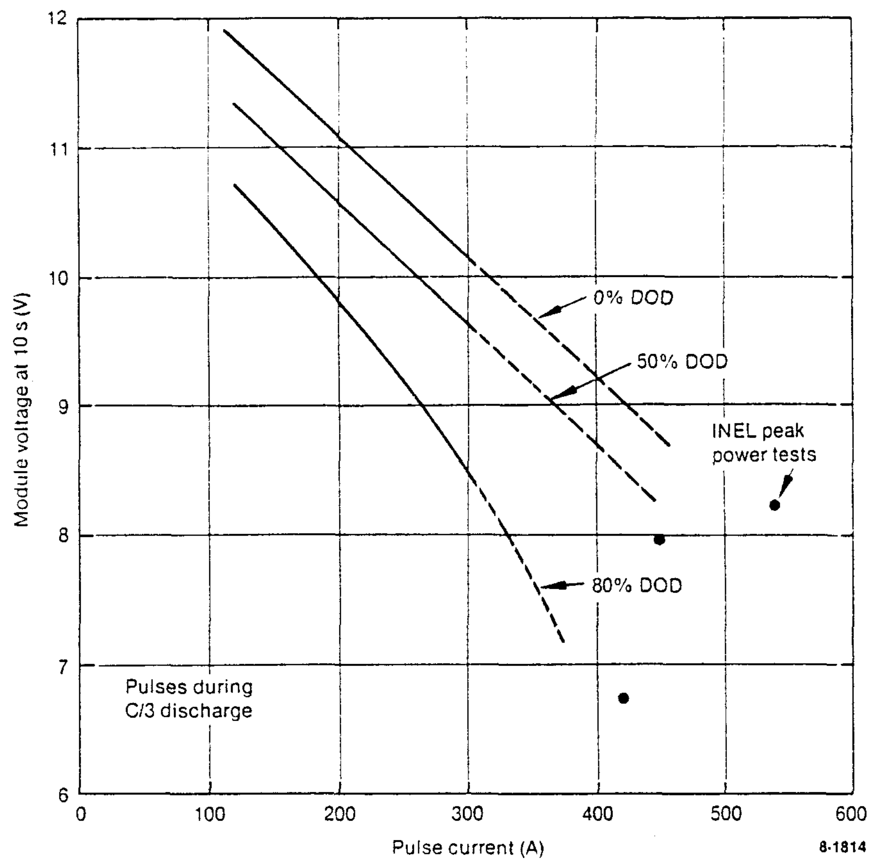

Figure 13. Pulse tests of the ETX-I battery at Lucas Chloride.

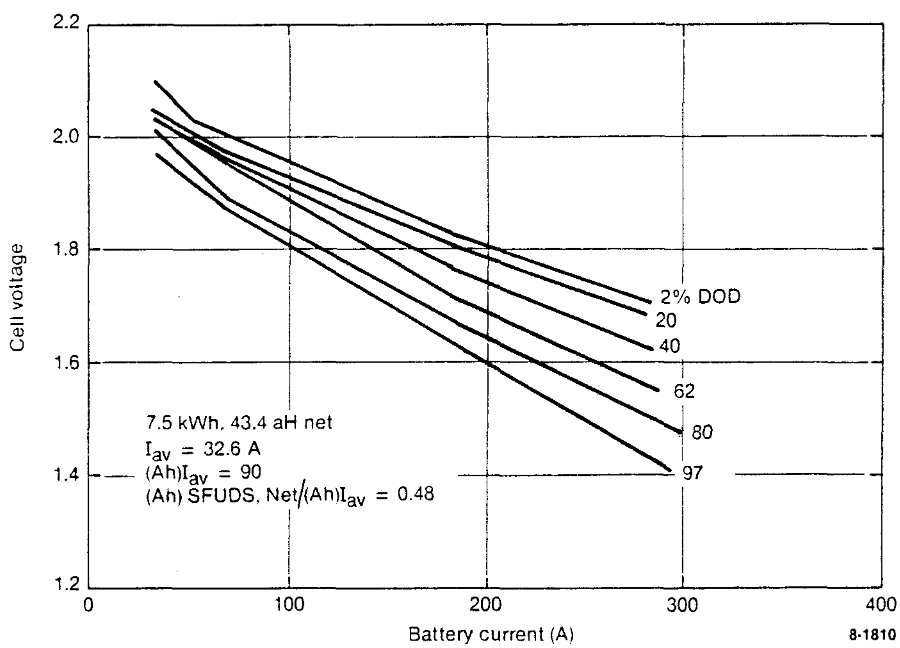

Figure 14. Voltage vs I, DOD for the ETX-I battery from SFUDS tests.

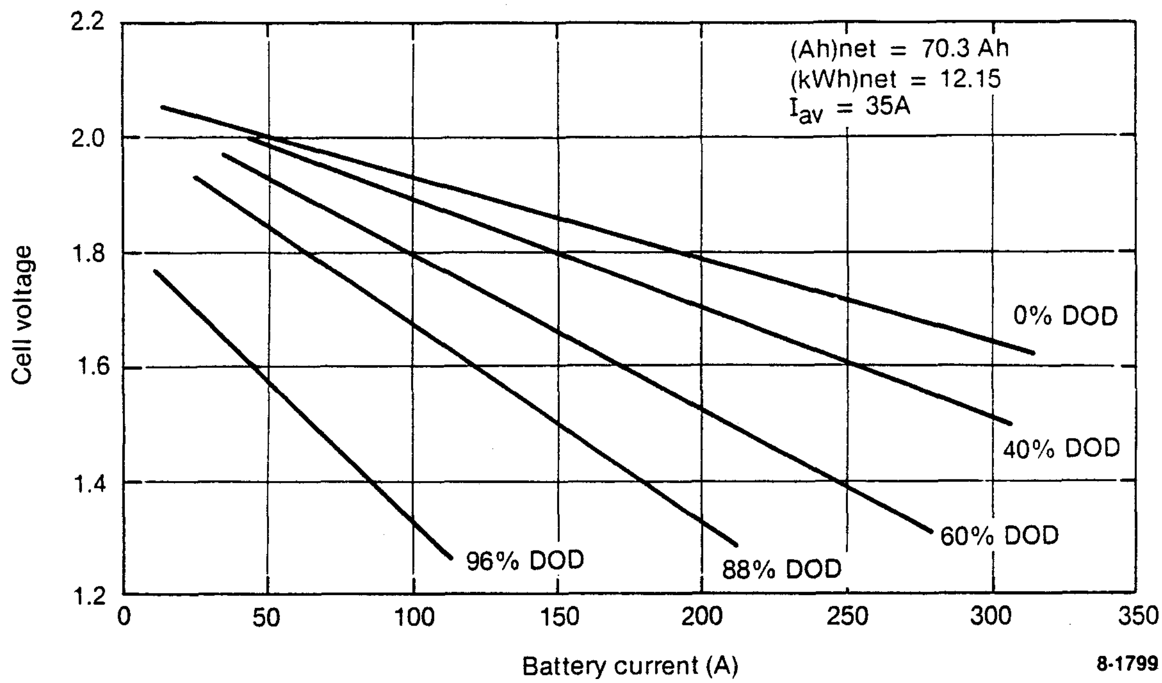

Figure 15. Voltage vs I, DOD for the ETX-I battery from vehicle FUDS tests.

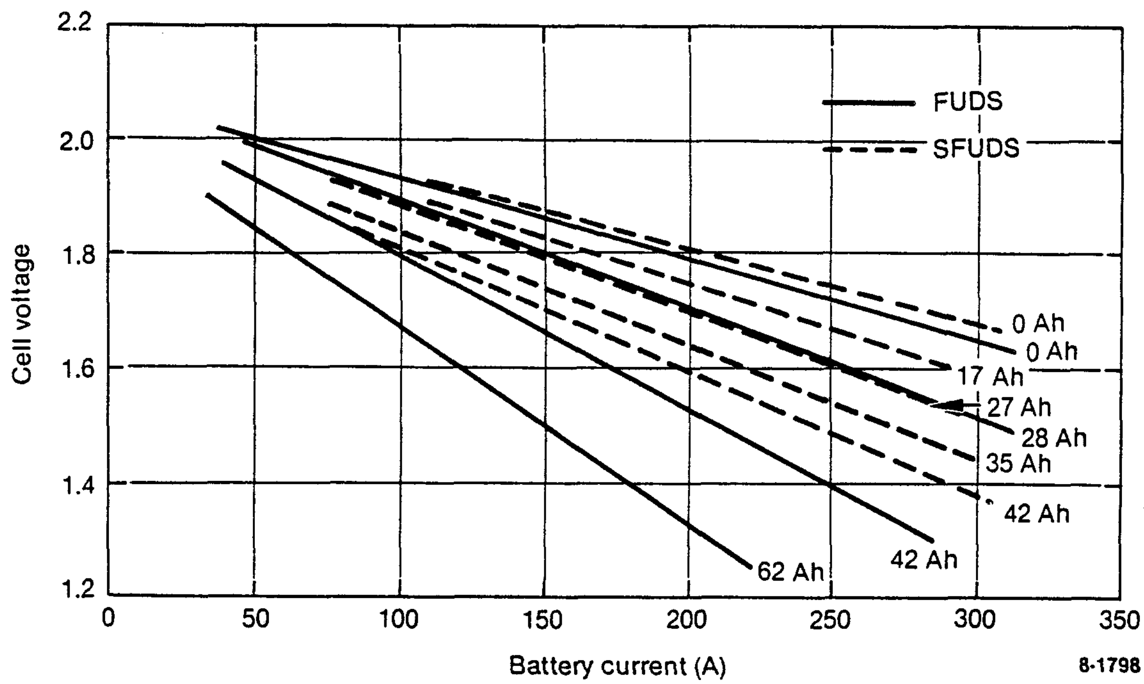

Figure 16. Comparison of SFUDS and FUDS V vs. I, DOD characteristics at various Ah discharge conditions.

The maximum battery power at this point in the test was only about 15 kW, corresponding to a power density of 30 W/kg. The average current in both tests was about 35 A. This difference between tests can be circumvented by comparing the voltage-current characteristics using Ah withdrawn at a particular time to track battery state rather than DOD. Figure 16 shows that, when this is done, the SFUDS and FUDS data are in much better agreement than would have been the case if the comparison had been made using DOD. The Ah used is the net value, which includes the effect of regenerative braking currents.

The FUDS pulsed discharge data (Figure 15) can also be compared with the data obtained by Lucas Chloride in their pulse discharge tests at the 3 h rate (average current of 32 A). The battery capacity in the Lucas Chloride tests was 94 Ah. Hence, 50% DOD corresponds to 47 Ah withdrawn and 80% DOD to 75 Ah. Figure 17 shows the Lucas Chloride and FUDS voltage-current data compared using the net Ah withdrawn as the indication of battery discharge state. The figure shows clearly that the method of pulsing the battery at widely spaced time intervals during a discharge at the average current does not yield a good indication of battery power capability for use in electric vehicles in stop-go urban driving in which relatively frequent high current pulses occur. The reason for this is that when the high current pulses are widely spaced in time the battery has time to recover from the effect (polarization) of the previous high current pulse. This explains why the measured capacity of the ETX-I battery on the FUDS and SFUDS tests was less than expected based on the Lucas Chloride tests of the modules. This will be discussed later when the results of the dynamometer tests of the ETX-I vehicle are presented and analyzed.

6. ETX-I VEHICLE TEST RESULTS

6.1 Test Program and Procedures

A series of tests of the ETX-I test vehicle powered by the ETX-I lead-acid battery were performed in the INEL Vehicle Dynamometer Laboratory. The test program is summarized in Table 5 and the data for each test is given in Appendix D. The procedures for testing electric vehicles at the INEL follow closely those recommended in the revised SAE J227 Electric Vehicle Test Procedure 5. A general exception is the number of tests of each type performed. At the INEL two rules are used (1) tests of the same type are never consecutive, and (2) only two tests (instead of the recommended three) are run for each type if the gross energy consumption of the first two agree to within 3%. When the difference of the first two tests is greater than 3%, a procedure/equipment investigation is performed. If no clear reason for the variation can be determined, a third test is run and the three test results are averaged.

If modifications to test procedure, equipment, or the vehicle are required, the third test result is averaged with the closest result from the first two tests. This method of operation sometimes requires a fourth test to be performed in order to obtain an acceptable average value.

The Electric Vehicle Test Procedure (SAE J227) allows the testing organization the option of selecting only those tests required to meet their needs. The INEL did not perform the Deceleration Tests (SAE-J227; Section 12) and Propulsion System Thermal Performance Tests (Section 13). The Gradeability at Speed Test (Section 9) was attempted on the INEL dynamometer, but the absorption capability of the dynamometer was not sufficient to hold the vehicle at the required speeds. Thus the analytical method of determining gradeability at speed from maximum acceleration data is used in this report.

6.2 Dynamometer Test Results

6.2.1 Energy Consumption

The energy consumption (Wh/km from the battery) of the vehicle at various speeds can be determined from constant speed range tests or from a special energy economy test in which the vehicle is driven at a number of speeds (32, 40, 48, 56, 64, 72, 80, 88 km/h) for a duration of 60 s at each speed. The sequence of speeds is repeated at selected battery states-of-charge (100, 60, 40, 20%) with the battery being discharged at the C/3 rate between sequences. The results of the energy economy tests are given in Figure 18. The energy consumption values from the 48, 64, and 88 km/h constant speed range tests are also shown in Figure 18.

The constant speed data are consistent with that from the energy economy tests in that they lie, as expected, slightly above the energy economy curves after the vehicle has warmed-up. The battery powers (kW) at the various constant speeds and battery states-of-charge are given in Table 6.

Energy consumption at various constant speeds, based on dynamometer data taken at Ford, is given in Reference 1, Vol. I. The Ford values and the INEL data for a warmed-up vehicle are compared in the table below:

	Energy Consumption (Wh/km)		
Speed (km/h)	INEL	Ford	Corrected* % difference
40	118	101	9.0
56	124	106	9.0
72	136	124	2.2
88	153	150	-5.1

* Corrected to account for the different test weights at Ford and INEL

The road load of the ETX-I vehicle at constant speed was 7% higher in the INEL tests than in the Ford tests, because the same coastdown curve was used in both tests, but not the same test weight (1590 kg at Ford and 1705 kg at INEL). As indicated in the table, the energy consumption data from Ford have been corrected to account for the difference in test weight. When this is done, the two sets of data differ by less than 10%.

The energy consumption results for various driving schedules from the range tests on the dynamometer at INEL are given in Table 7. Values are shown with/without the energy used from the auxilary battery. The difference between the gross and net energy consumption values for the variable power FUDS and J227 C and D cycles represent the effect of the energy returned to the battery by regenerative braking. The INEL and Ford energy consumption values for the J227 D and the FUDS cycles are compared in the table below. The values given are for cycles after the vehicle system has been completely warmed-up as that is considered by Ford to be the proper value to use when assessing the powertrain energy consumption. Both sets of data include auxilary power and wheel friction losses and the vehicle being shutoff during the rest period of the FUDS.

Energy Consumption (Wh/km)

Test Cycle	INEL	Ford	Corrected[a] %Difference
J227 D	176	172	-4.6
FUDS	201	172	9.0

a Corrected to account for the different test weights at Ford and INEL

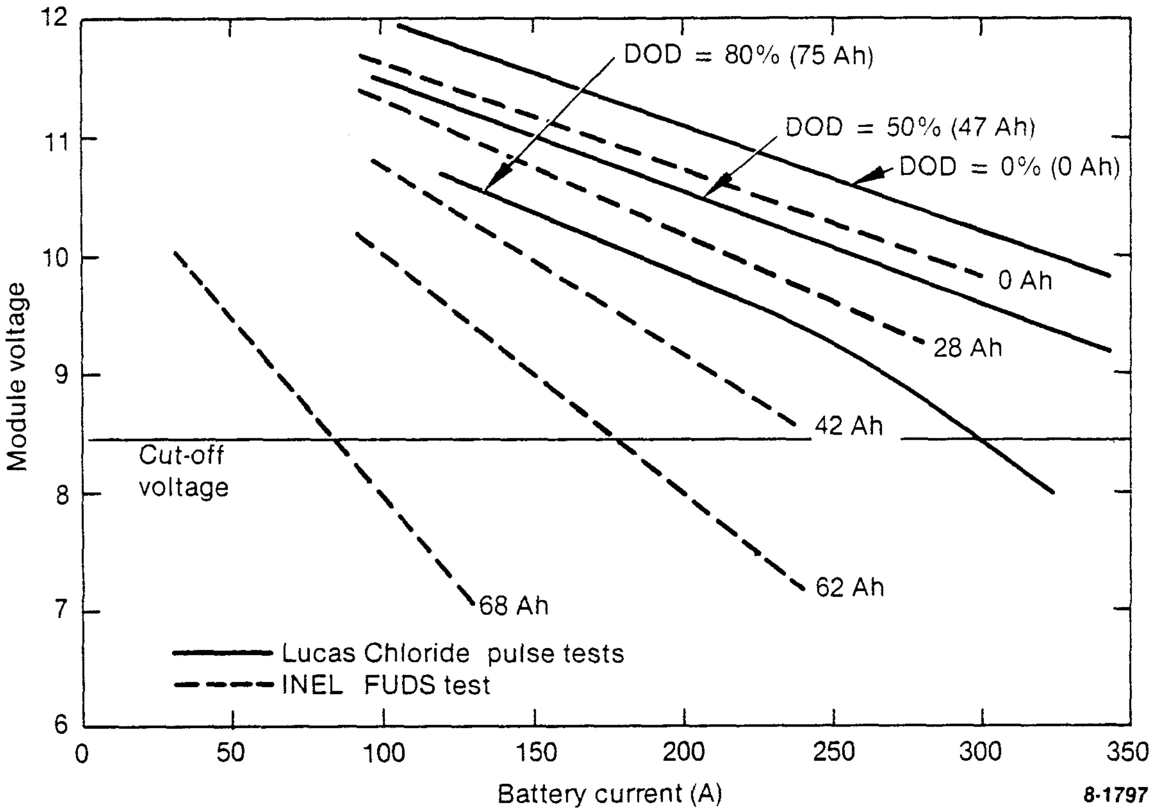

Figure 17. Comparison of the Lucas Chloride pulse test and INEL FUDS V vs. I. Ah characteristics.

TABLE 5. DYNAMOMETER TEST SUMMARY

Test Type		Number of Tests Performed
48 km/h	Accessories off	4
48 km/h	Accessories on	2
64 km/h	Accessories off	4
88 km/h	Accessories on	4
Cycle	No regeneration	2
D-Cycle	Split regeneration	2
D-Cycle	Parallel regeneration	4
D-Cycle	Noncontinuous - parallel regeneration	3
C-Cycle	No regeneration	2
C-Cycle	Split regeneration	2
C-Cycle	Parallel regeneration	3
C-Cycle	Noncontinuous - parallel regeneration	2
FUDS	Split regeneration	2
FUDS	Parallel regeneration	4
SFUDS	Parallel regeneration	2
Acceleration	- -	2
Energy Economy	- -	2
	TOTAL	46

TABLE 6. ETX-I CONSTANT SPEED POWER (kW)

Speed (km/h)	Battery State of Charge 100%	60%	40%
32	5.24	4.27	4.21
40	6.22	5.20	5.12
48	6.94	6.13	5.99
56	7.95	6.98	7.07
64	9.18	8.34	8.19
72	10.47	10.11	9.72
80	12.33	11.73	11.52
88	14.33	13.92	13.80

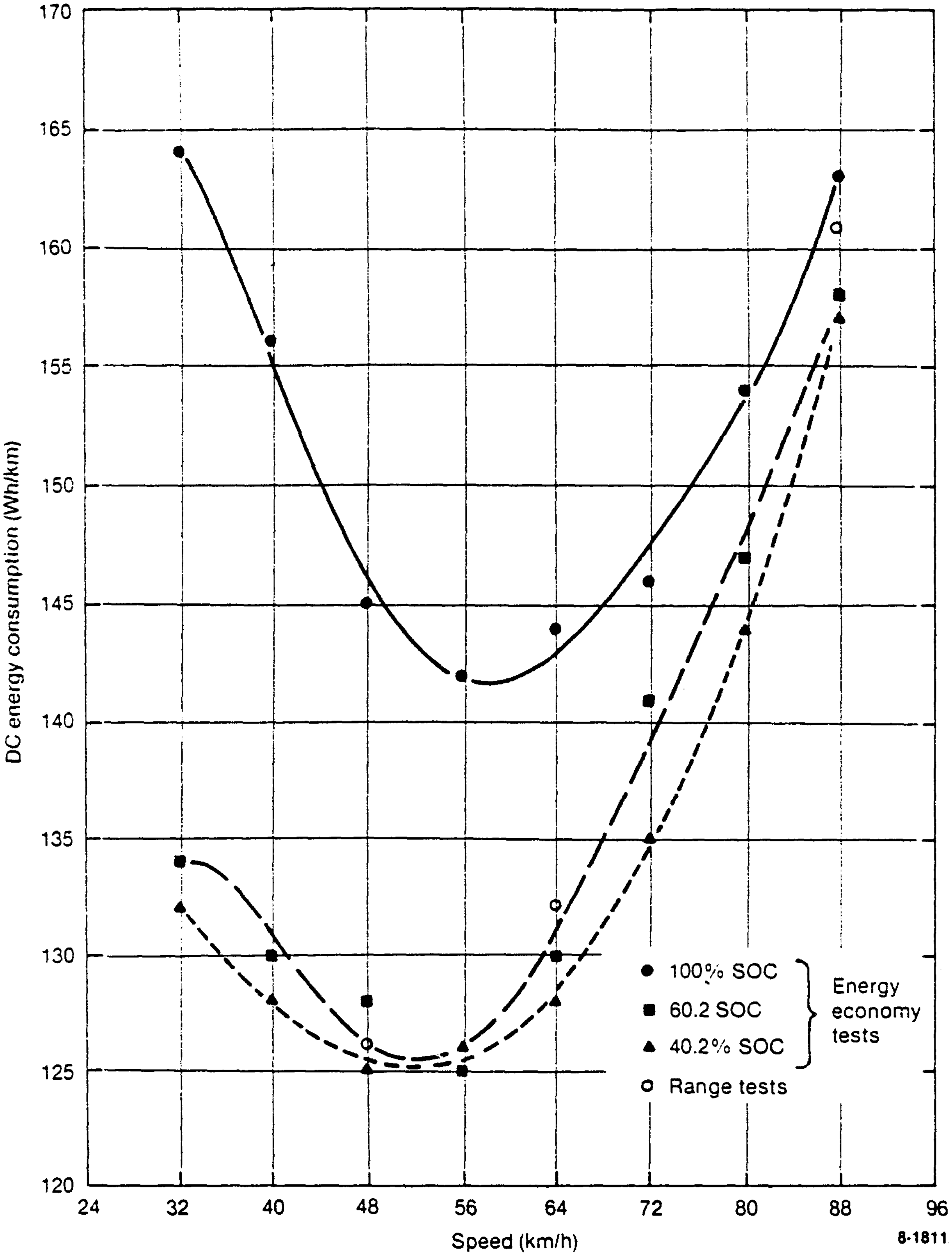

Figure 18. ETX-I vehicle DC energy consumption at various constant speeds.

TABLE 7 ETX-I SUMMARY TEST RESULT

Test Type	Range (km)	Energy Consumption (Wh/km) ac[a]	System (dc)[a]	Gross (dc)	Net (dc)	Gross[a] (dc)	Net[a] (dc)	Number of Tests
48 km/h	125.67	204	183	126	126	129	129	4
64 km/h	101.52	257	231	133	132	135	134	4
88 km/h	66.64	331	295	160	160	161	161	4
D-Cycle parallel regen	59.47	334	302	200	182	204	186	4
D-Cycle parallel regen (non continuous)	60.61	422	376	201	182	205	186	3
D-Cycle split regen	58.04	358	320	198	177	202	181	2
D-Cycle no regen	52.76	381	339	201	201	204	204	2
C-Cycle parallel regen	63.20	359	322	211	197	217	203	3
C-Cycle parallel regen (non continuous)	65.14	414	341	209	194	214	199	2
C-Cycle rplit regen	64.88	333	300	212	193	219	201	2
C-Cycle no regen	63.09	399	351	216	216	223	223	2
FUDS parallel regen	61.88	381	344	222	204	229	211	4
FUDS split regen	59.63	354	322	222	201	229	208	2
S-FUDS parallel regen	61.96	429	382	210	196	218	204	2

Acceleration - Average time (s) and battery SOC of two tests.

	100% SOC	54% SOC	33% SOC	11% SOC
0 to 48 km/h	7.4	8.4	9.3	10.9
40 to 80 km/h	16.0	17.9	20.8	33.4
0 to 80 km/h	21.3	23.9	27.7	40.8
0 to 88 km/h	29.8	33.5	39.7	59.5
Peak Battery Power, Average (kw)	45.3	39.4	36.5	28.8
Battery Volt Range, Average (v)	209 to 164	199 to 156	195 to 145	189-133V

Energy Consumption Definitions

$$\text{ac} = \frac{\text{ac Energy to Charger for Recharge}}{\text{Distance Traveled}} \qquad \text{Vehicle dc Gross} = \frac{\text{dc Energy from Battery While Driving (not including Regen Benefit)}}{\text{Distance Traveled}}$$

$$\text{System dc} = \frac{\text{dc Energy From Charger for Recharge}}{\text{Distance Traveled}} \qquad \text{Vehicle dc Net} = \frac{\text{dc Energy from Battery While Driving including Regen Benefit}}{\text{Distance Traveled}}$$

a. Includes auxiliary battery energy used during the test

As in the case of the constant speed tests, the energy consumption values should be corrected to account for the difference in the test weight at Ford and INEL. Both the road load and inertia forces in the INEL tests were 7% higher than at Ford. Hence, correcting the energy consumption for the 7% higher vehicle weight used at the INEL, the difference in the INEL and Ford data is at most 9%. While the Ford test results indicate the ETX-I powertrain met almost exactly the program goal for energy consumption on the FUDS cycle (see Table 2), the INEL results indicate the ETX-I powertrain energy consumption was slightly greater (about 9%) than the program goal at the Ford test weight of 1590 kg.

6.2.2 Range and Battery Capacity

This section of the report is concerned primarily with the range of the ETX-I test vehicle on various driving schedules and the capacity of the ETX-I battery for those driving conditions. Of special interest will be the behavior of the battery at low states-of charge near the range limit of the vehicle for the FUDS and SFUDS driving cycles.

The range of the ETX-I for various speeds and driving cycles is given in Figure 19. In constant speed driving, the range decreases monotonically with speed being 128 km at 48 km/h and 67 km at 88 km/h. The range on the variable speed, stop-go driving cycles is about 60 km varying only slightly between the various driving cycles. For all the dynamometer tests the battery temperature at the beginning of the test was 25C ± 2C. At the end of the tests the battery temperature was 31C ± 2.5C.

The battery capacity for constant speed driving is shown in Figure 20 in terms of the the Ragone curve for the battery and the kWh withdrawn as a function of the power density of the discharge. Note in Figure 20 the battery characteristics found from the vehicle dynamometer tests lie between the Ragone curves obtained from the pre and posttests of the ETX-I battery in the Battery Test Laboratory. The initial battery temperatures and increases in temperature during the tests were essentially the same in both the Battery and Dynamometer Laboratory testing of the ETX-I battery (see Appendix C and D).

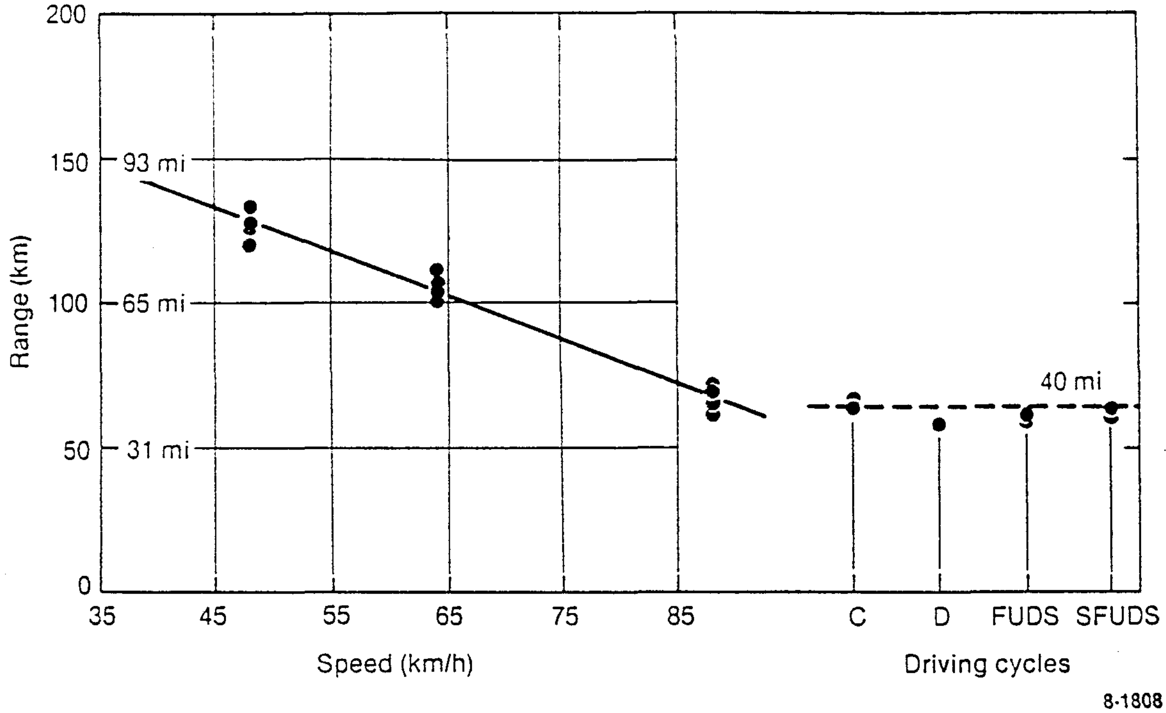

Figure 19. Range of the ETX-I test vehicle for various speeds and driving cycles.

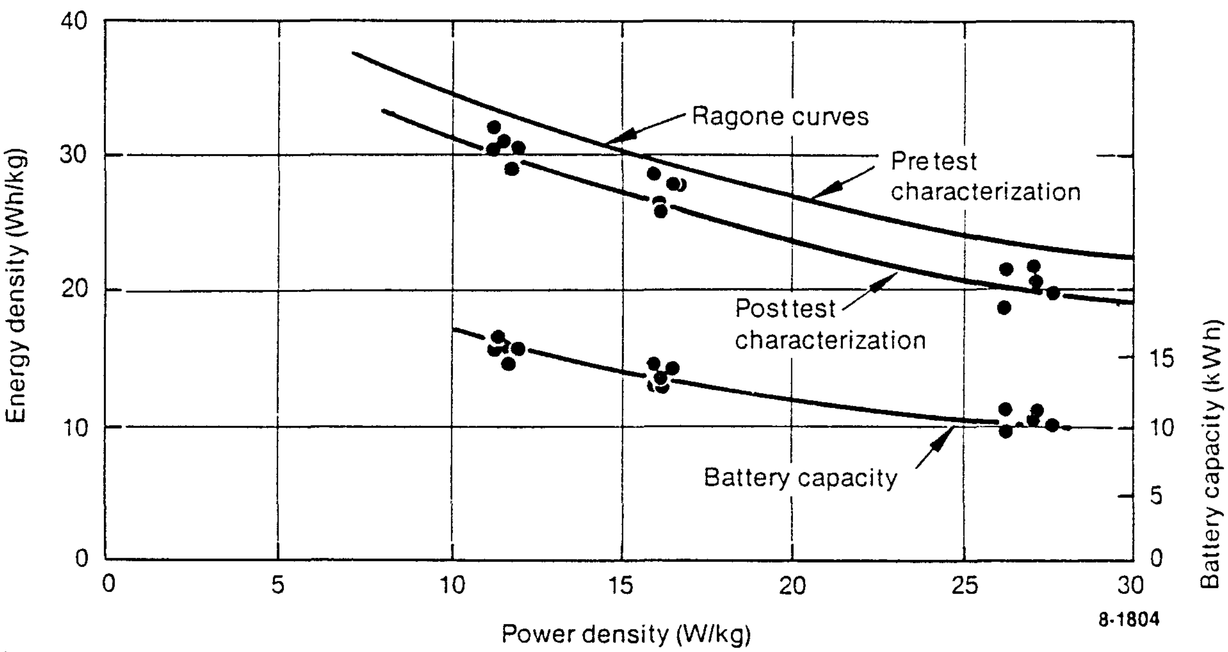

Figure 20. Battery capacity and Ragone curves determined from vehicle constant speed tests on the dynamometer.

The marked decrease in vehicle range with speed is caused by to the increase in vehicle energy consumption (see Table 7) and the decrease in battery kWh capacity (see Figure 20) at the higher speeds. The reason that the ranges for the variable speed driving cycles vary only slightly from cycle to cycle is that both the vehicle energy consumption (not including auxilary energy) and the battery kWh capacity change by relatively small factors as shown in the following table:

Driving Cycle	Wh/km	Iav(A)	Ah	kWh	Range(km)
FUDS	199	37	70.6	11.9	60
SFUDS	196	36	72.0	12.1	62
J227 D	176	48	60.5	10.2	58
J227 C	197	29	73.7	12.8	65

The battery capacity for a particular driving cycle depends primarily on the average discharge current(Iav) for the cycle and secondarily on the peak power requirements of the cycle.

The ETX-I test vehicle was tested at Ford on the dynamometer for the FUDS driving cycle. Data taken from Reference 1, Vol. I are given in the table below for comparison with the corresponding INEL data. The Ford data shown in the table were obtained from a different set of tests than those from which the previously discussed powertrain energy consumption values were derived.

Ford Vehicle Dynamometer Data for the FUDS

Ah	Iav	kWh	Range(km)	Wh/km
59.9	42.2	12.2	59.6	205
70.9	31.3	14.4	70.9	203
72.5	30.4	14.3	72.5	197
78.9	34.3	14.5	73.0	199

The Ford and INEL vehicle data for energy consumption (uncorrected) over the FUDS cycle agree to within 1 to 2% even though the range and battery capacity were higher in the Ford tests. It should be noted that the energy consumption in the vehicle FUDS cycle tests at Ford is 15 to 20% higher than reported by Ford from their powertrain energy consumption tests. The reason for this inconsistency in the Ford data is not clear even after discussions with Ford.

The greater range and battery capacity at Ford indicate the ETX-I battery was closer to its rated capacity in the early tests at Ford than it was for the later tests at INEL. The battery characterization tests at INEL showed that the battery continued to lose capacity during dynamometer tests at INEL (see Figures 9 and 10).

Vehicle range and battery capacity for a particular test are dependent on the test termination criteria used in the test program and how they are applied. This is particularly true for driving cycles, such as the FUDS, which require high peaks in battery power to follow the cycle very closely, although the cycle can be followed approximately even when the battery is capable of much lower peak power. The ETX-I can follow the FUDS very closely when the battery is at a high SOC. As shown in Figure 21, battery power peaks as high as 45 kW occur during the first FUDS cycle. However, most of the time the battery power peaks are between 15 to 20 kW. As the battery SOC decreases, the battery is no longer able to meet the peak power required to follow the cycle closely at all times maintaining the minimum pack voltage of 134 V set by the motor controller. Note from Figure 21 at a time of 8100 s (about 48 km into the FUDS test at the maximum acceleration point in the fifth cycle) that the peak power is only 31 kW for a voltage slightly above 130 V. This corresponds to a power density of only 60 W/kg. The battery can continue, however, to supply the power required to follow the FUDS cycle to a good degree of approximation. As the FUDS test continues and the battery is further discharged (the Ah withdrawn increases), the battery voltage droops to 140 V and below for battery power peaks of only 20 to 25 kW. Finally the battery reaches the state-of-discharge at which it can supply a peak power of only 15 kW at 134 V and the test is terminated, because the vehicle can no longer even follow the FUDS cycle during the accelerations to 56 km/h. This sequence of changes in battery response during discharge on the FUDS cycle is shown in Figure 21.

Criteria for termination of dynamometer tests of electric vehicles are given in the Reference 5-SAE J227 EV Test Procedures. For most of the FUDS cycle, the test should be terminated if the vehicle lags behind the prescribed vehicle-time schedule by 3 km/h (2 mph) for more than two seconds.

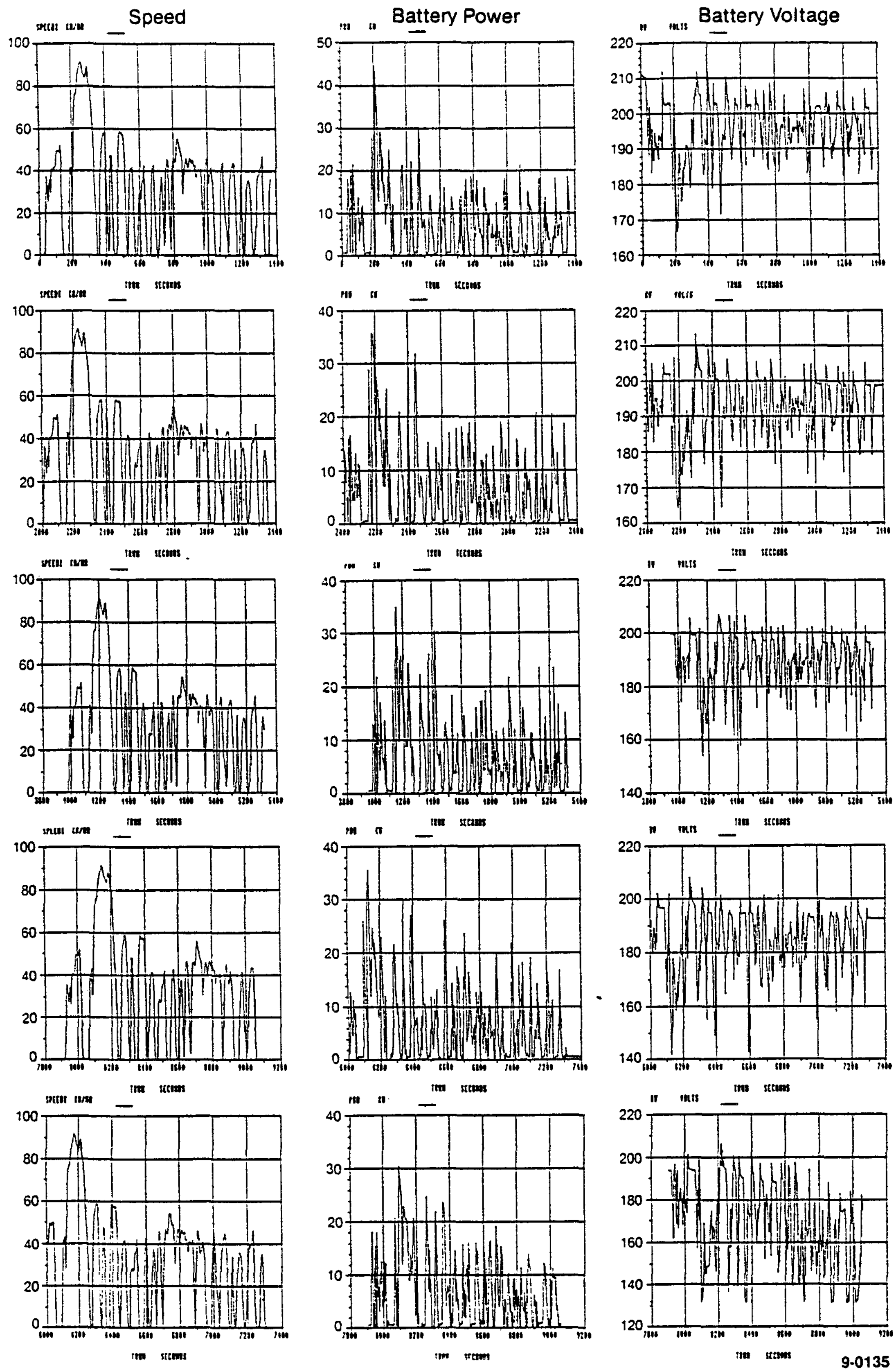

Figure 21. Speed, battery power, and battery voltage data for the FUDS Cycle.

During the high velocity acceleration portion of the cycle between 187 to 240 s, the end-of-test criterion is relaxed to permit the test to be continued if the vehicle can attain a minimum speed of 72 km/h (45 mph) within 30 s after the 187 second mark and then holds that speed until the 305 second mark. It is difficult to determine how closely these criteria have been followed in most of the electric vehicle range tests reported in the literature as that would require detailed velocity-time data near the end of test for each test. Such data for a ETX-I FUDS test at the INEL are shown in Figure 22 for the 1st, 5th and 6th cycles. The strict SAE J227 criterion is satisfied for the 5th cycle and not for the 6th cycle. The relaxed criterion is satisfied for the 6th cycle, but the test was terminated at 380 s when the vehicle could not satisfy the strict criterion during one of the low speed accelerations. Hence the range of the ETX-I vehicle on the FUDS test was about 63 km (5*12 km/cycle plus a fraction of a cycle) as stated previously in this section. The maximum battery power during the 5th FUDS cycle was 33 kW and the vehicle was barely able to follow the velocity-time schedule within the strict allowable tolerance. The corresponding battery power density is about 65 W/kg based on module weight. Hence a SFUDS battery test terminated at that same power density for a cut-off voltage of 1.395 V/cell (134 V for the 16 module pack) corresponds to a vehicle dynamometer test terminated when the vehicle can just follow the velocity schedule using the strict criterion. Termination of the SFUDS battery test at a power density of about 30 Wh/kg corresponds to a vehicle dynamometer test terminated using the relaxed J227 termination criterion.

6.2.3 Regenerative Braking

The ETX-I test vehicle is equipped with two modes of regenerative braking. In the "split" mode of regeneration, hydraulic braking is always available on the rear wheels and electric regenerative braking only is applied to the front wheels until the braking demanded exceeds the maximum regenerative capability. The second regenerative mode is called the "parallel" mode. In this mode, electric and hydraulic braking are applied together at the front, driven wheels regardless of braking demand. The effect of regenerative braking on energy consumption for the J227 C and D cycles is shown in Table 8.

TABLE 8. THE EFFECT OF REGENERATIVE BRAKING ON ENERGY CONSUMPTION FOR VARIOUS DRIVING CYCLES.

Cycle	Energy Consumption (Wh/km)	Decrease (%)
D-Cycle		
No regeneration (baseline)	204	--
Parallel regeneration	186	8.8
Split regeneration	181	11.3
C-Cycle		
No regeneration (baseline)	223	--
Parallel regeneration	203	9.0
Split regeneration	201	9.9

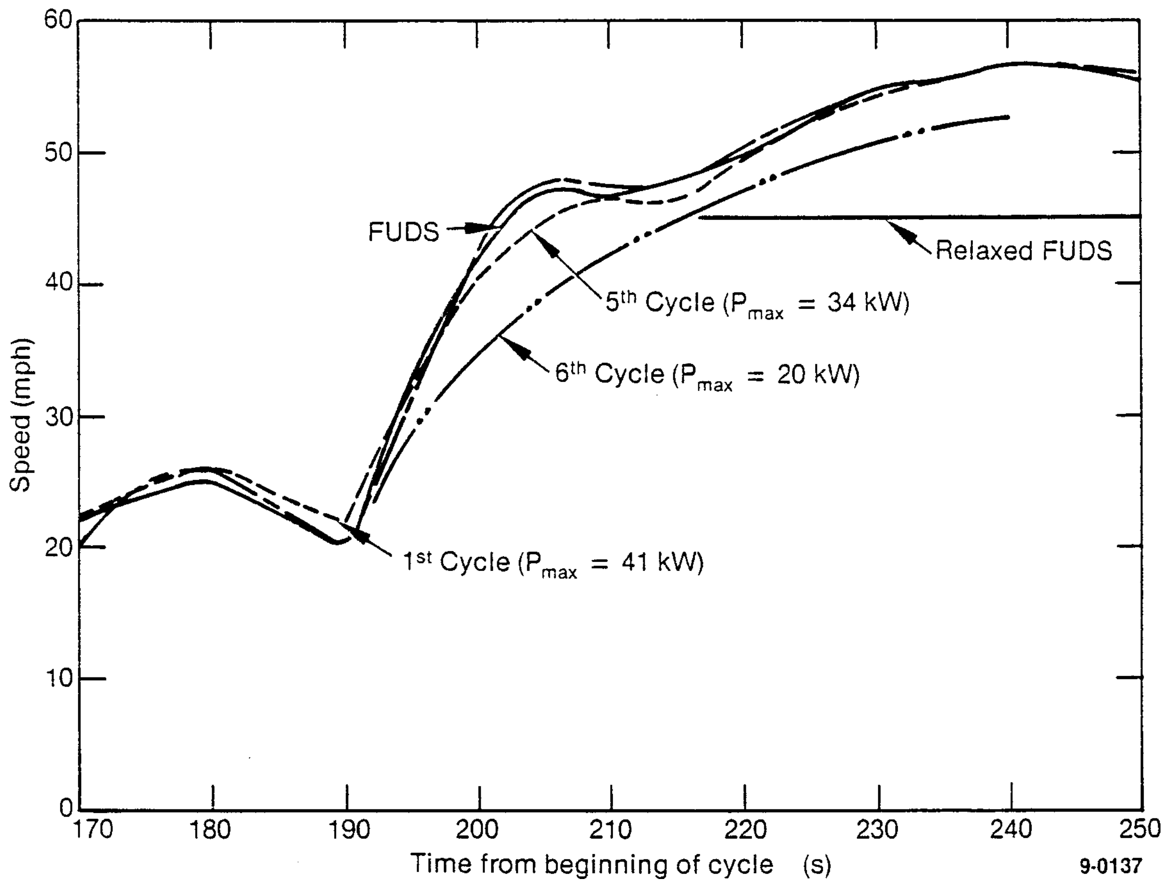

Figure 22. Comparison of vehicle speed and FUDS schedule during the high speed acceleration portion of the cycle.

The energy consumption is decreased about 9% in the "parallel" mode and about 10.5% in the "split" mode. These values were calculated by dividing the total energy returned to the battery during the test to the total energy withdrawn from the battery. This approach to determining the effect of regeneration on energy consumption neglects the difference between the voltage during charge and discharge and thus slightly overestimates its effect. The effect of regenerative braking on range would be expected to be about 10% based on its effect on energy consumption. The range data presented previously in Figure 19 includes the effect of "split" mode regeneration.

6.2.4 Vehicle Acceleration and Gradeability

The maximum effort acceleration of the ETX-I test vehicle was determined on the dynamometer. Acceleration tests were performed at nominal battery states-of-charge of 100, 60, 40, and 10%. Two accelerations were run at each battery SOC. Between the sets of accelerations, the vehicle was driven at a constant speed such that the battery was discharged at the C/3 rate. The results of the acceleration tests are shown in Figures 23 and 24. The acceleration times, taken from Figure 23, are summarized in the table below:

	Acceleration Times (s)			
SOC	100%	54%	33%	11%
0 to 48 km/h	7.2	8.3	9.1	11.0
0 to 80 km/h	22.0	25.0	29.0	41.5
0 to 88 km/h	30.5	34.5	41.0	60.0

Ford tested the ETX-I on the track (Reference 1, Vol. I) and measured acceleration times of 6.7-8.0 seconds for 0 to 48 km/h and 18 to 24 s for 0 to 80 km/h depending on the battery SOC. Ford indicated the battery condition by noting the voltage range observed during the acceleration. The battery power and voltage during the INEL acceleration test at 100% SOC are shown in Figure 25. The voltages in the INEL test at 100% SOC are slightly lower than those observed by Ford during their fastest accelerations at the highest battery SOC, but higher than those observed by Ford during accelerations at lower battery SOC.

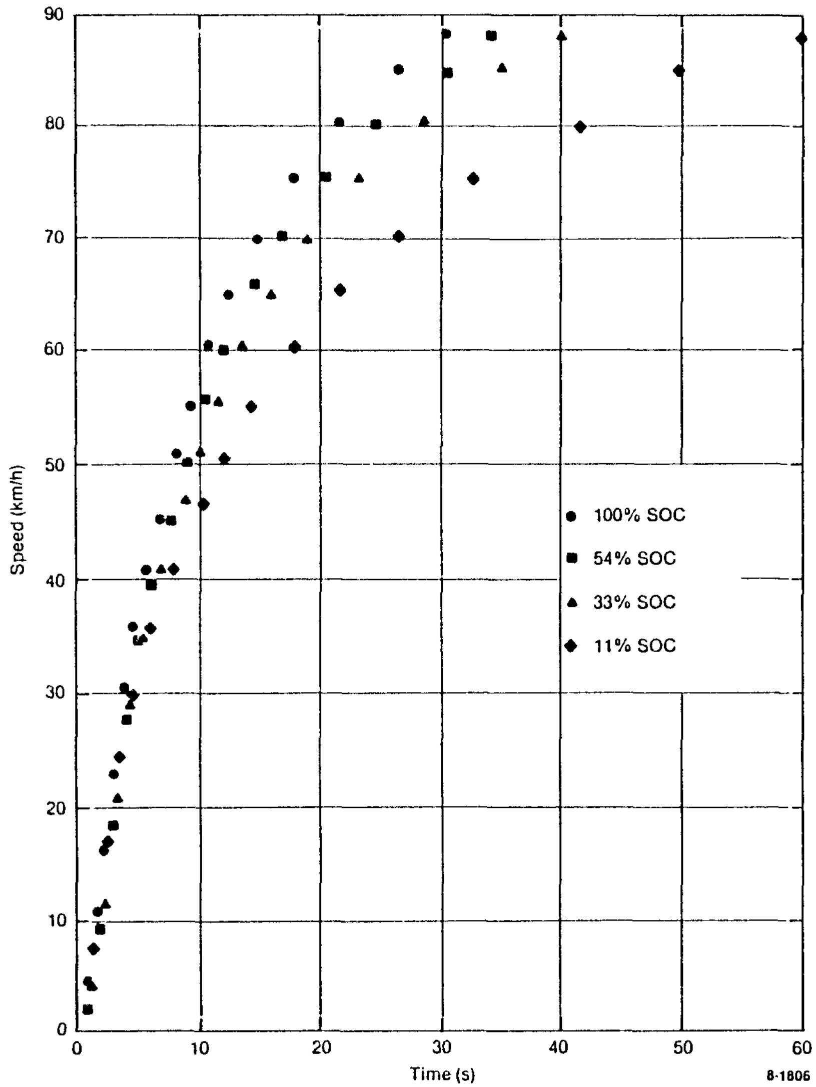

Figure 23. ETX-I acceleration curves at various states-of-charge.

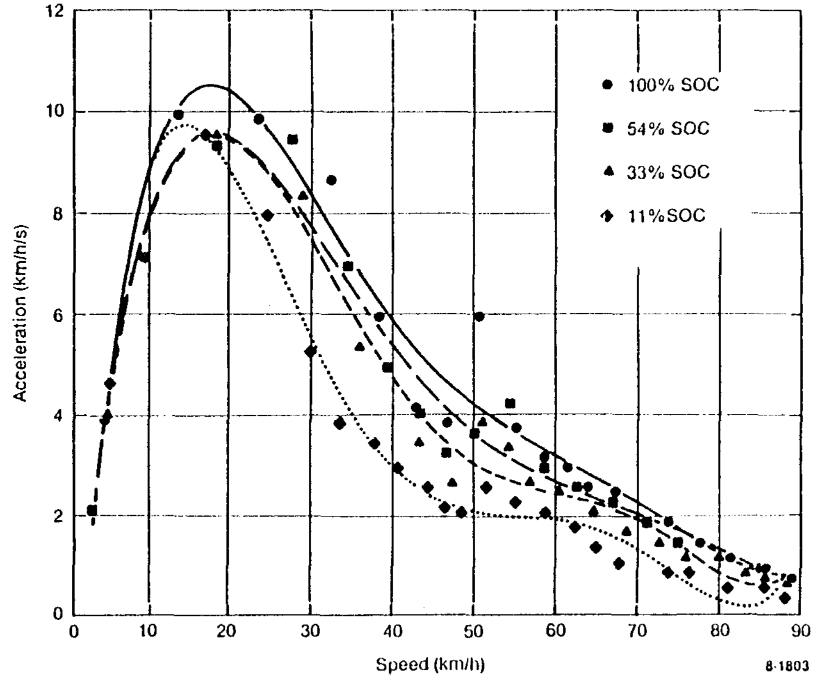

Figure 24. ETX-I acceleration rates at various speeds and states-of-charge.

Hence it seems reasonable to conclude that the INEL and Ford vehicle acceleration data are in good agreement at comparable battery SOC.

The ETX-I shows excellent times for accelerations up to 72 km/h (45 mph) and less attractive times to higher speeds. The reason for the reduced acceleration rates at higher speeds is that, as shown in Figure 25, the maximum effort electrical power decreases from a peak of 45 kW to less than 30 kW at 88 km/h. This occurs because the output power of the ETX-I motor peaks at about 5000 RPM and decreases at higher motor speeds.

The percent gradeability at speed (G@S) can be calculated from acceleration rate versus speed data (Figure 24) using the relation

$$G@S = 100 \tan (\sin^{-1} 0.0283\ A)$$

where G@S = %

A = acceleration in km/h/s

The results of the calculation for various battery states-of-charge are given in Figure 26. The maximum gradeability at low speed is about 30%. The gradeability decreases with speed becoming less than 2% for speeds greater than about 75 km/h for low battery SOC.

6.3 Battery Management System Test Results

6.3.1 Introduction

The battery management system (BMS) for the ETX-I battery was described previously in Section 3.2. In this section, operating experience with the BMS during the dynamometer tests of the ETX-I vehicle will be discussed. The operation of the BMS in the charging and discharge modes will be considered separately.

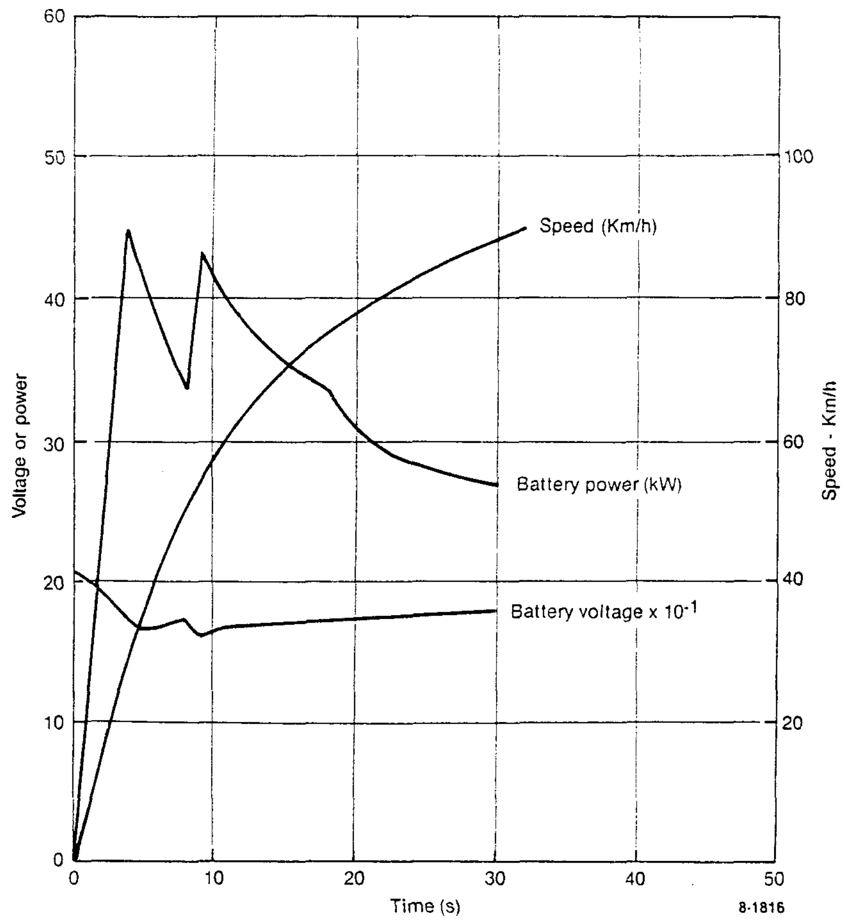

Figure 25. Speed and battery power and voltage during a maximum effort acceleration.

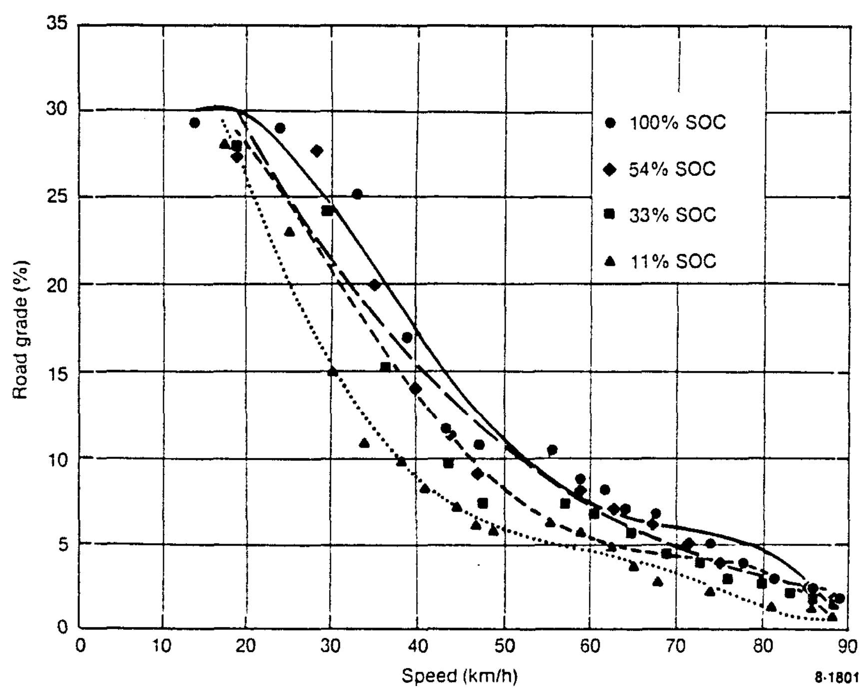

Figure 26. ETX-I gradeability at speed at various states-of-charge.

6.3.2 The Charging Mode

At the outset of the dynamometer tests of the ETX-I, battery recharging was done using the BMS and the microprocessor controlled on-board charger. As the test program proceeded, the data seemed to indicate that the battery capacity was gradually decreasing. It was suspected that this decrease in capacity was occurring because the charger was not fully recharging the battery after each test. Hence it was decided to return the battery to the Battery Laboratory to assess its capacity in standard discharge tests and to use the Spegel charger to recharge the battery in all further tests (after January 12, 1988) in the Dynamometer Lab. The Spegel charger, which is an off-board charger supplied by Lucas Chloride for charging their batteries, was used for all the tests in the Battery Laboratory. Subsequent tests in the Battery and Dynamometer Laboratories indicated that the ETX-I battery had lost capacity, but that the reason for this loss was not because of the undercharging by the BMS on-board charger.

In the charging mode, the BMS charger software was designed to control the overcharge of the battery in a regular charge to that needed to maintain battery capacity and to provide periodic equalization charges of an additional 25 Ah. The charger was programmed to perform an equalization charge every Sunday if at least 400 Ah had been used from the battery in the preceding week. As indicated by the battery test summary given in Appendix C, the BMS charger did not provide equalization charges once a week on Sunday and it occasionally initiated a premature equalization charge two or three cycles after the last equalization charge. The overcharge factor for the equalization charges performed by the BMS charger was 60-65%, which seemed rather high. No equalization charges were done when the Spegel charger was being used. The overcharge factor for the Spegel charger was about 27%. The reason for the degradation in battery capacity at INEL may have been the large overcharge given the battery in equalization charges by the BMS on-board charger.

Data on the charging of the ETX-I battery during the INEL tests in both the Battery and Electric Vehicle Dynamometer Laboratories are given Appendix C. The charging characteristics are shown in Figure 27 where the ampere-hr overcharge factor and dc energy efficiency at the battery terminals (both in percent) are given as a function of Ahs withdrawn from the battery during the preceding discharge. The data shown indicate a battery overcharge factor between 20 to 30% for most discharges and an energy efficiency between 60 to 70%. The charging characteristics were essentially the same for both the BMS and Spegel chargers.

Some flooded-plate lead-acid batteries are more efficient than the ETX-I battery in that they require an overcharge factor of only 15 to 16% and have a dc energy efficiency of 70 to 75%.

6.3.3 Discharge Mode (State-of-Charge Indicator)

The function of the battery management system during discharge is to indicate the battery SOC to the driver by way of meter reading on the dash of the vehicle. In the ETX-I vehicle, the standard gasoline gauge is used as the meter to display the SOC reading. The SOC algorithm, which is described in some detail in Reference 1, Vol. II, utilizes the rate compensated Ah withdrawn from the battery to determine its state-of-charge at SOC greater than about 50% and a voltage that is corrected for the effects of polarization to determine SOC at lower states-of-charge.

State-of-charge data were taken during the dynamometer tests of the ETX-I to check the accuracy of the SOC algorithm used in the BMS. The SOC meter on the dash is marked only in increments of 1/4 of full capacity (as is standard for a gas gauge), so it was not possible to read the SOC with sufficient accuracy to evaluate the SOC algorithm. Software was available to read the battery parameters (calculated SOC, Ah in and out, Ah capacity) from the memory of the BMS microcomputer during the vehicle test using an IBM XT. The data files were saved on floppy disks for later comparison with the battery measurements made routinely as part of the vehicle test. Comparisons of the BMS indicated SOC and the actual SOC from the battery data are given in Figures 28 to 32 for both constant speed and driving cycle tests.

Also shown in the figures are the SOC readings from the meter on the dash. The agreement between the indicated and actual SOC values is quite good especially at the higher SOC for which the BMS uses a rate dependent algorithm. At SOC <50%, where the BMS utilizes an inferred open-circuit voltage to determine state-of-charge, the agreement is not as good and the indicated SOC curve falls systematically below the actual SOC curve. One difficulty encountered occasionally with the BMS state-of-charge unit was that it did not properly initialize to SOC = 100% after a battery charge. This, of course, results in erroneous SOC readings as the battery discharges. Other electronic problems, such as susceptibility to electronic noise from the motor controller, were also encountered at times, but in general the SOC function of the BMS worked quite well for the various driving schedules.

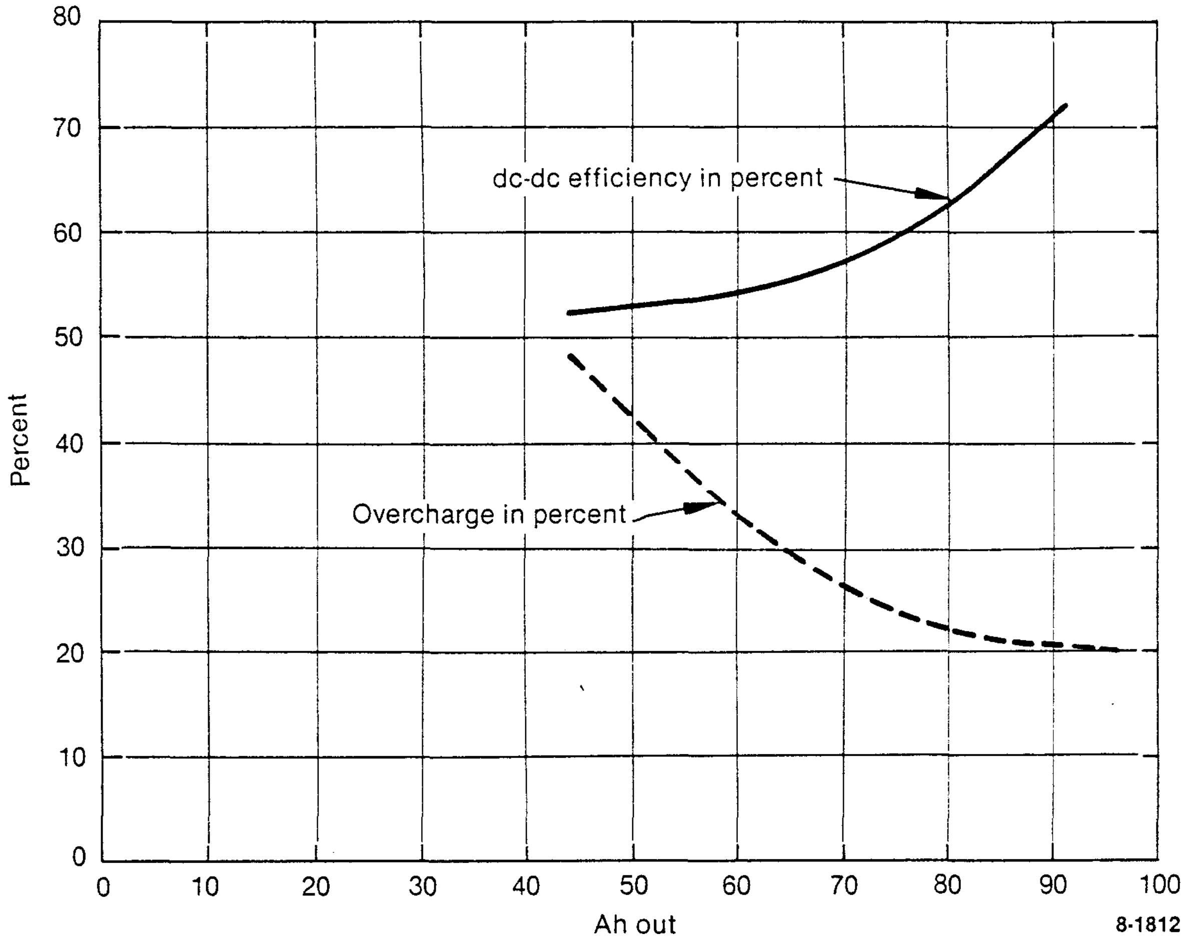

Figure 27. ETX-I battery charging characteristics.

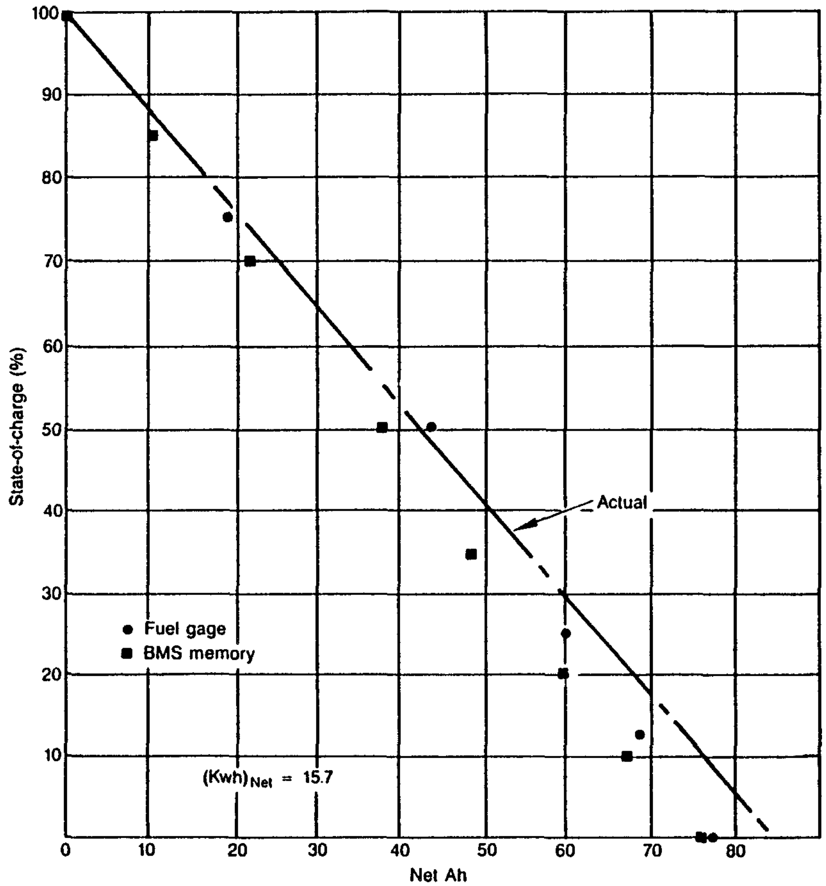

Figure 28. Comparison of Indicated and Actual State-of-Charge for the ETX-I Battery (48 Km/hr)

8-8148

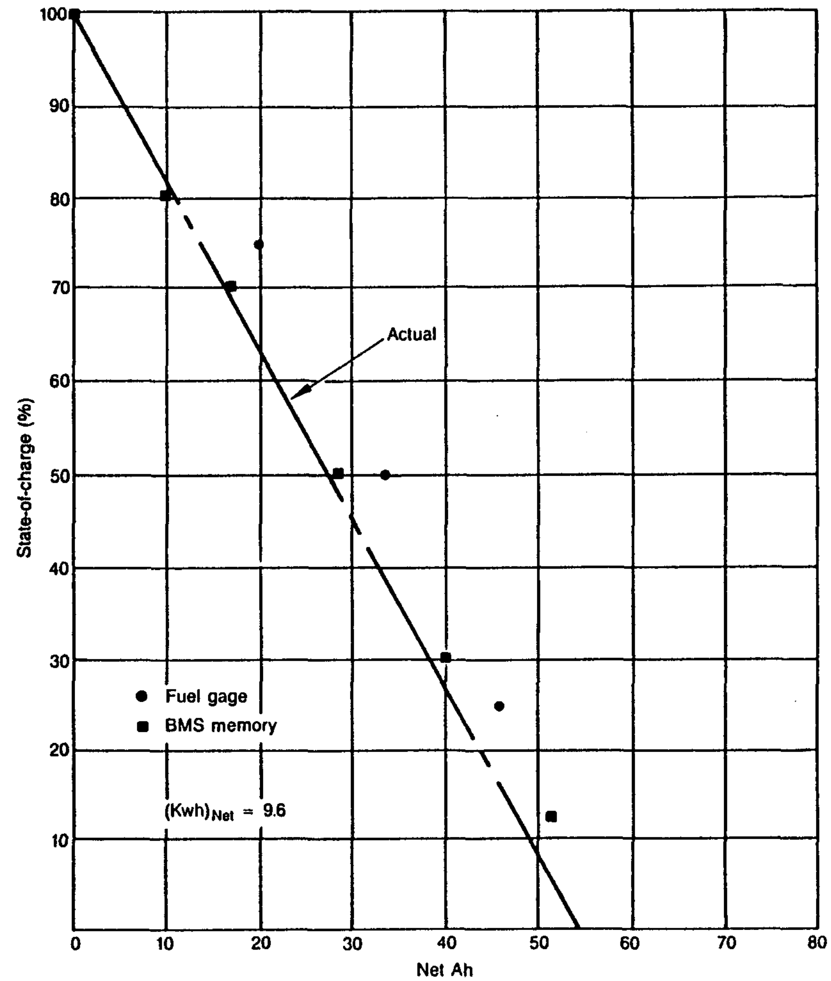

Figure 29. Comparison of Indicated and Actual State-of-Charge for the ETX-I Battery (88 Km/hr)

8-8150

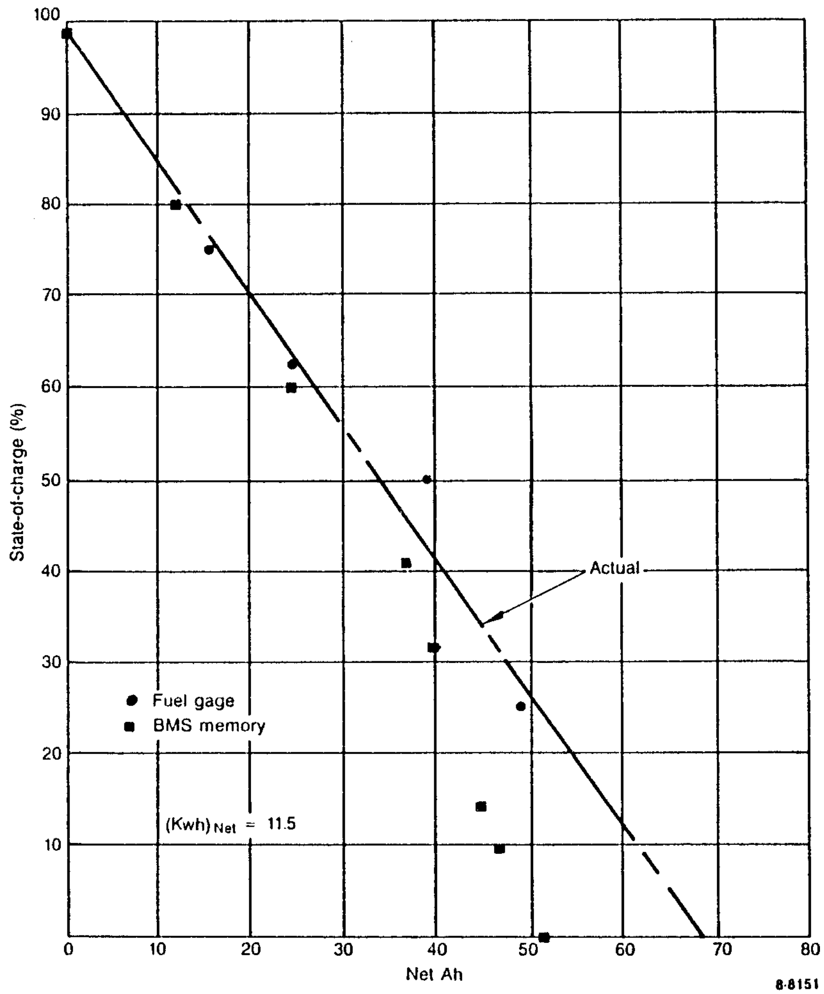

Figure 30. Comparison of Indicated and Actual State-of-Charge for the ETX-I Battery (FUDS Cycle)

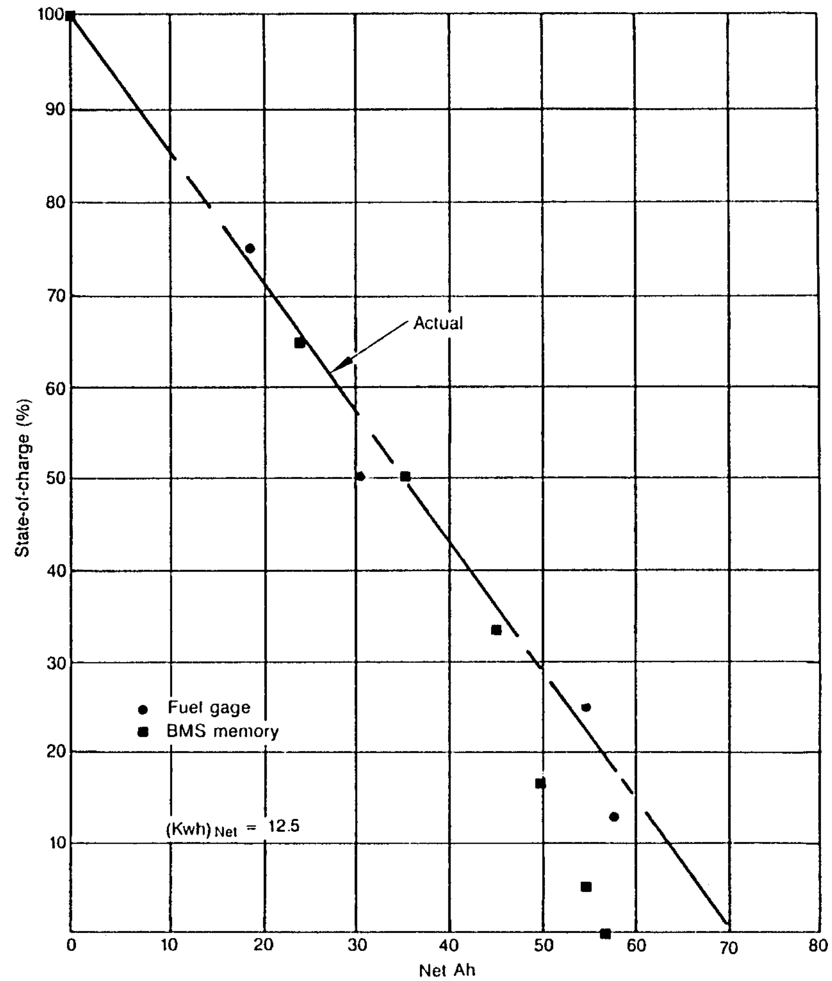

Figure 31. Comparison of Indicated and Actual State-of-Charge for the ETX-I Battery (C Cycle with Regeneration)

8-8149

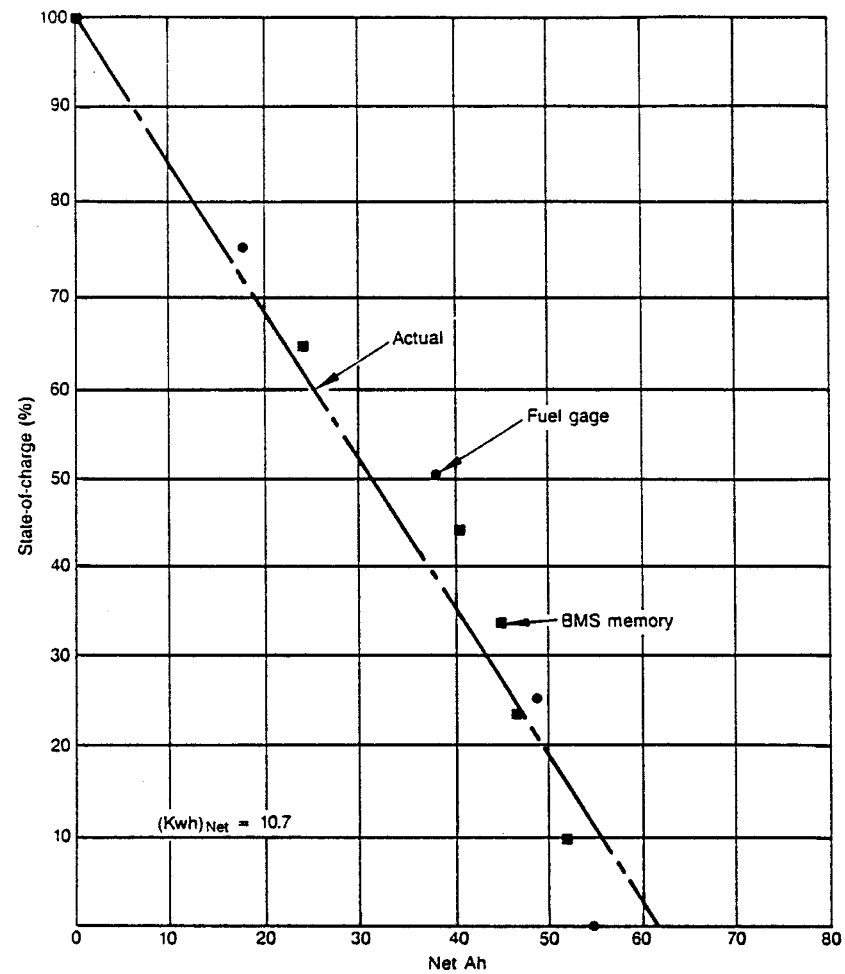

Figure 32. Comparison of Indicated and Actual State-of-Charge for the ETX-I Battery (D Cycle without Regeneration)

8-7964

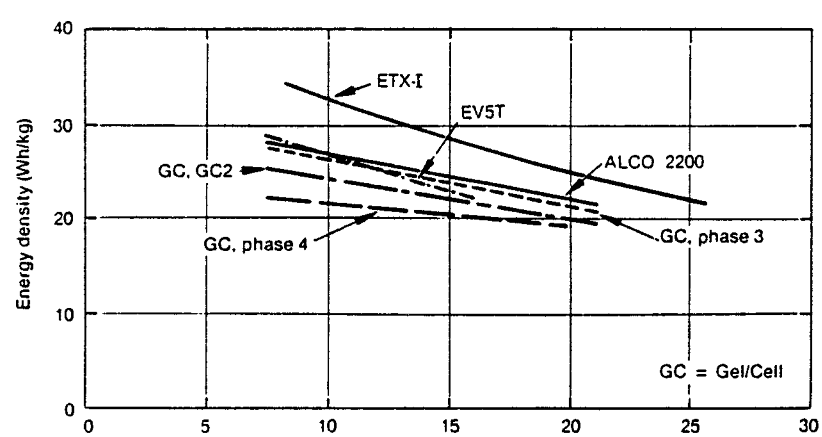

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Figure 33. Ragone curves for various lead-acid batteries.

7. COMPARISONS WITH OTHER VEHICLES AND BATTERIES

7.1 Introduction

The previous sections of this report were concerned with the characteristics and performance of the ETX-I test vehicle and the ETX-I battery. In this section, the ETX-I vehicle and battery are compared with other vehicles and batteries tested in the INEL Battery and Electric Vehicle Dynamometer Laboratories in the last several years. Of particular interest will be comparisons between the ETX-I and the ETV-1 vehicles.

7.2 Comparisons With Other Lead-acid Batteries

A number of lead-acid batteries have been tested in the INEL Battery Test Laboratory. These include the ALCO 2200, the Chloride EV5T, and three Johnson Control Gel-cell batteries - Phase 3, Phase 4, and the GC2. The Ragone curves of these batteries are compared with the Ragone curve of the Lucas Chloride ETX-I battery in Figure 33. The Ragone curve shown for the ETX-I battery is the mean of the pre-test and post-test results which is in good agreement with the battery characteristics found from the constant speed dynamometer tests. Figure 33 indicates that the ETX-I battery has greater capacity than the other lead-acid batteries by 15 to 35% with the maximum difference occurring at the lower power densities. The voltage, current, SOC characteristics of the ETX-I and Gel-cell batteries are compared in Figures 34 A and B. It is evident from the figure that the tubular plate ETX-I battery has a higher resistance than the Gel-cell battery and in addition, the resistance of the ETX-I battery increases significantly as the SOC decreases. Hence, it is expected that the higher capacity of the ETX-I battery would not be completely utilized in vehicle applications that demand high power as was the case with the ETX-I vehicle at high vehicle speeds and on the FUDS driving cycle.

7.3 Comparisons With Other Vehicles

The ETX-I test vehicle is compared with other electric vehicles tested at the INEL in Table 9.

The table shows the physical characteristics of the vehicles as well as various performance parameters, including energy consumption, range, and acceleration times.

It is of particular interest to compare the ETX-I with the ETV-1, which has served as the reference vehicle for the evaluation of various battery systems in past studies at INEL and JPL. The data given in Table 9 indicate that the ETV-1 has significantly lower energy consumption and longer range than the ETX-I. The ETX-I has faster acceleration than the ETV-1 up to 80 km/h due to its higher power motor and two-speed transmission. A detailed comparison of the ETX-I and ETV-1 vehicles is given in Reference 6.

The relatively short range of the ETX-I is due primarily to its relatively high energy consumption and not to the ETX-I battery having lower performance than other available lead-acid batteries. This can be seen by calculating the constant speed range of the ETV-1 using the ETX-I battery in place of the Phase 3 Gel/cell batteries with which it has been tested and found to have good range[7].

The results of that calculation are shown in Figure 35 compared with the range of the ETV-1 with the Phase 3 Gel-cell battery and the ETX-I with the ETX-I battery. The use of the ETX-I batteries in place of the Phase 3 Gel-cell batteries increases the range of the ETV-1 vehicle by 8 to 15%. The estimated range of the ETV-1 on the FUDS cycle using the ETX-I battery is 81 km, which is an increase of 8% over that measured using the Phase 3 Gel-cell battery[7].

Comparisons of powertrain component efficiencies for the ETX-I and the ETV-1 vehicles at constant speeds between 40 and 88 km/h are given in Figure 36. Also shown in the figure are the powertrain system efficiencies for the vehicles. The efficiencies for the ETV-1 were taken from Reference 8 and are based on JPL test data for the ETV-1 vehicle. The efficiencies for the ETX-I were determined from the tabular component data in Reference 1 and calculated values for motor output power and shaft speed.

TABLE 9. INEL ELECTRIC VEHICLE TESTING SUMMARY

VEHICLE SPECIFICATIONS			
Vehicle Designation	Bedford Van	Eaton AC-3	Eaton DC
Weight (kg)			
Test	3490	1641	1723
Curb [a]	2658	1352	1588
Gross Veh. [b]	3500	c	c
Rolling Resistance Coeff. (kg/kg)	0.0104	0.0098	0.0098
Frontal Area (m^2)	3.35	1.84	1.84
Aero Drag Coeff. (C_D)	0.47	0.43	0.43
Drag Area Product- C_DA (m^2)	1.57	.79	.79
Power-to-weight ratio (W/kg) [d]	12	21	17
Motor	dc	ac	dc
Peak Power (kW)	40	33.6	29.8
Maximum Speed (rpm)	6000	12,500	4500
Transmission	single-speed	two-speed	three-speed
BATTERY SPECIFICATION			
Manufacturer	Lucas Chloride (EV5T)	Sears Die Hard	ALCO 2200
Type	Tubular Lead Acid (36 x 6 V)	Lead Acid (16 x 12 V)	Lead Acid (18 x 6 V)
Weight (kg)	1134	385	545
Battery Mass Fraction	0.32	0.23	0.32
VEHICLE PERFORMANCE DATA			
Acceleration (s)			
0-48 km/h	11.6	11.2	12.5
0-80 km/h	64.8	22.0	36.4
0-88 km/h	-	28.5	47.5
Energy Consumption (Wh/km)			
48 km/h (vehicle net dc)	183	* -	-
72 km/h (vehicle net dc)	233	159	145
C-Cycle (vehicle net dc)	299	179	-
D-Cycle (vehicle net dc)	311	188	241
FUD-Cycle (vehicle net dc)	313	192	-
Range (km)			
48 km/h	182	e -	-
72 km/h	109	e -	79
C-Cycle	97	e -	-
D-Cycle	82	55.5	41
FUD-Cycle	77 [f]	e -	-
Gradeability (@ 32 km/h)	11%	18%	14%

a. Based on weighing the vehicle.

b. Assigned by developer/manufacturer.

c. Means no weight assigned because vehicle was a test bed.

d. Propulsion System Peak Power-to-weight (vehicle ratio).

e. Only minimal range data taken because of the use of marine batteries in place of EV batteries.

f. Best Effort.

TABLE 9. INEL ELECTRIC VEHICLE TESTING SUMMARY (Cont.)

VEHICLE SPECIFICATIONS			
Vehicle Designation	Chrysler/GE ETV-1	Ford/GE ETX-I	Evcort
Weight (kg)			
Test	1723	1705	1968
Curb [a]	1522	1566	1836
Gross Veh.[b]	1822	c	c
Rolling Resistance Coeff. (kg/kg)	0.0095	0.0097	0.0136
Frontal Area (m^2)	1.84	1.78	1.90
Aero Drag Coeff. (C_D)	0.32	0.42	0.35
Drag Area Product- C_DA (m^2)	0.59	0.75	0.67
Power-to-weight ratio (W/kg)[d]	17	25	19
Motor	dc	ac	dc
Peak Power (kW)	30	43	37
Maximum Speed (rpm)	5000	9000	6000
Transmission	single-speed	two-speed	five-speed
BATTERY SPECIFICATION			
Manufacturer	JCI Phase 3 Gel/Cell	Lucas Chloride	Concorde
Type	Lead Acid (18 x 6 V)	Tubular Lead Acid (16 x 12 V)	Sealed Lead Acid (18 x 6 V)
Weight (kg)	539	520	672
Battery Mass Fraction	0.31	0.31	0.34
VEHICLE PERFORMANCE DATA			
Acceleration (s)			
0-48 km/h	10.4	07.4	8.3
0-80 km/h	23.6	21.3	25.6
0-88 km/h	28.8	29.8	32.5
Energy Consumption (Wh/km)			
48 km/h (vehicle net dc)	94	129	119
72 km/h (vehicle net dc)	108	140	144
C-Cycle (vehicle net dc)	163	201	201
D-Cycle (vehicle net dc)	154	181	-
FUD-Cycle (vehicle net dc)	174	208	212
Range (km)			
48 km/h	172	128	154
72 km/h	126	92	108
C-Cycle	85	65	79
D-Cycle	82	58	-
FUD-Cycle	75	60	72
Gradeability (@ 32 km/h)	18%	25%	17

a. Based on weighing the vehicle.

b. Assigned by developer/manufacturer.

c. Means no weight assigned because vehicle was a test bed.

d. Propulsion System Peak Power-to-weight (vehicle ratio).

e. Only minimal range data taken because of the use of marine batteries in place of EV batteries.

f. Best Effort.

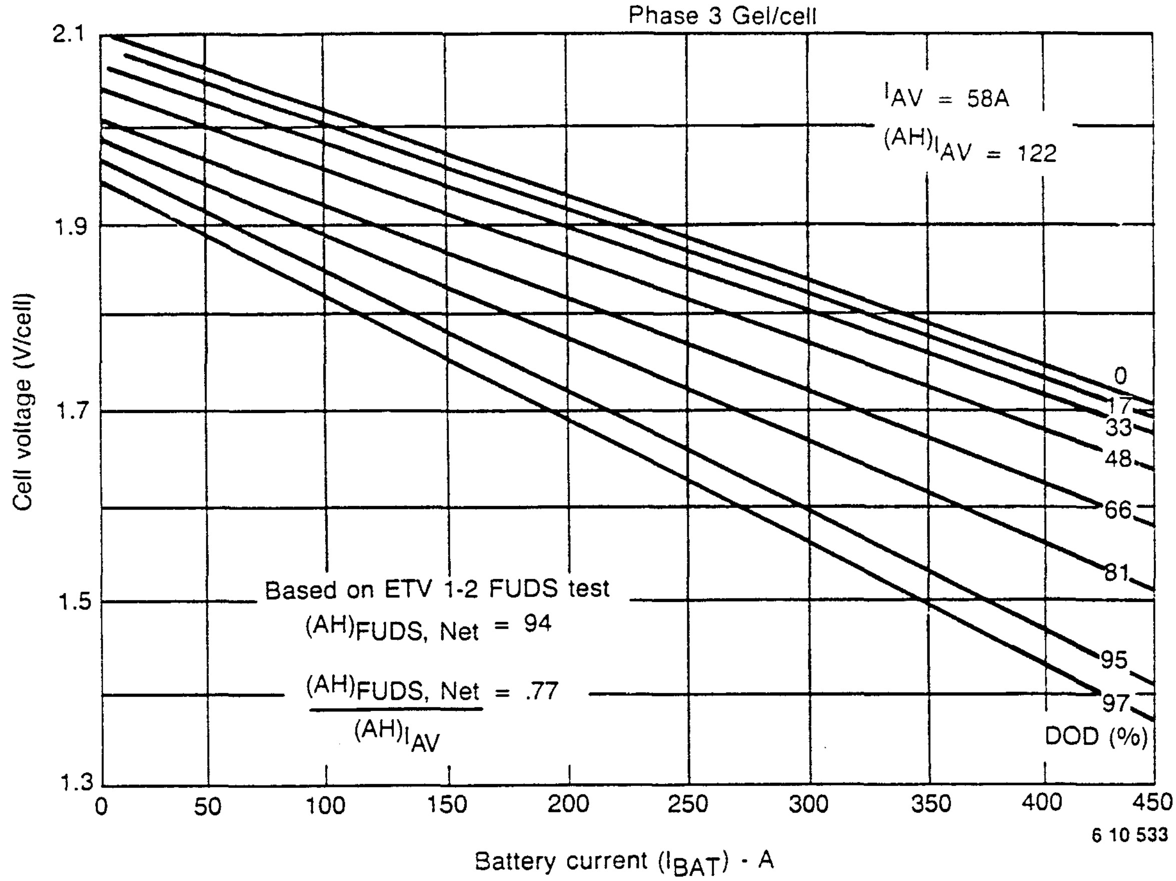

Figure 34a.

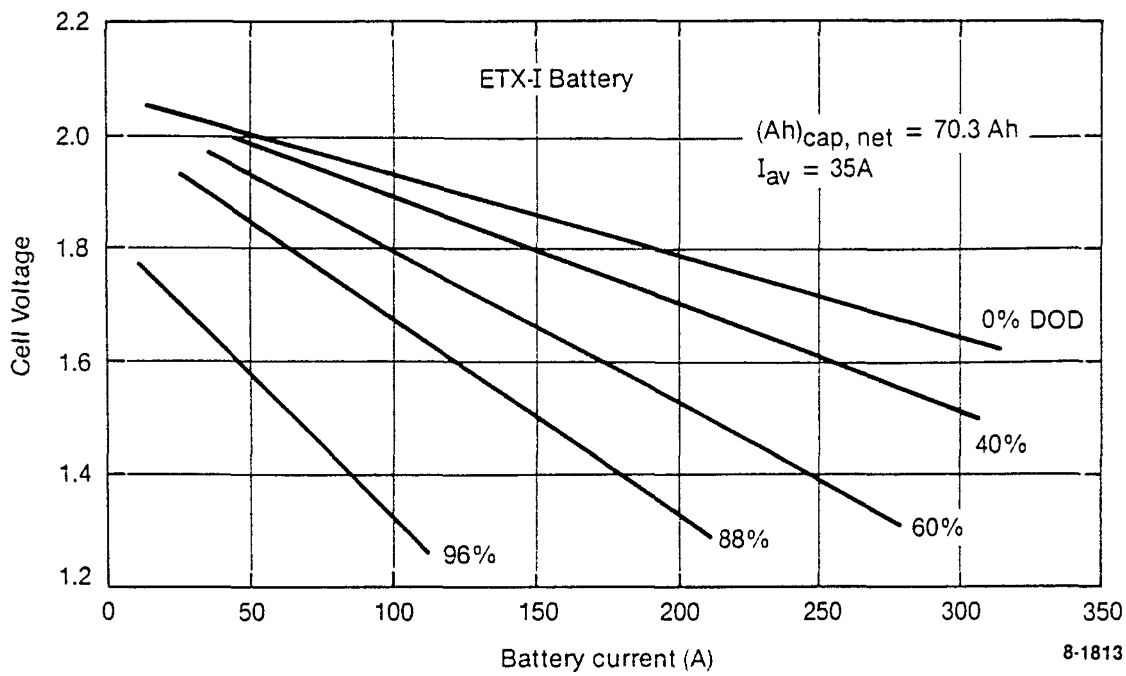

Figure 34b. Comparison of the V vs. I, DOD characteristics for the ETX-I and Phase 3, Gel/Cell batteries.

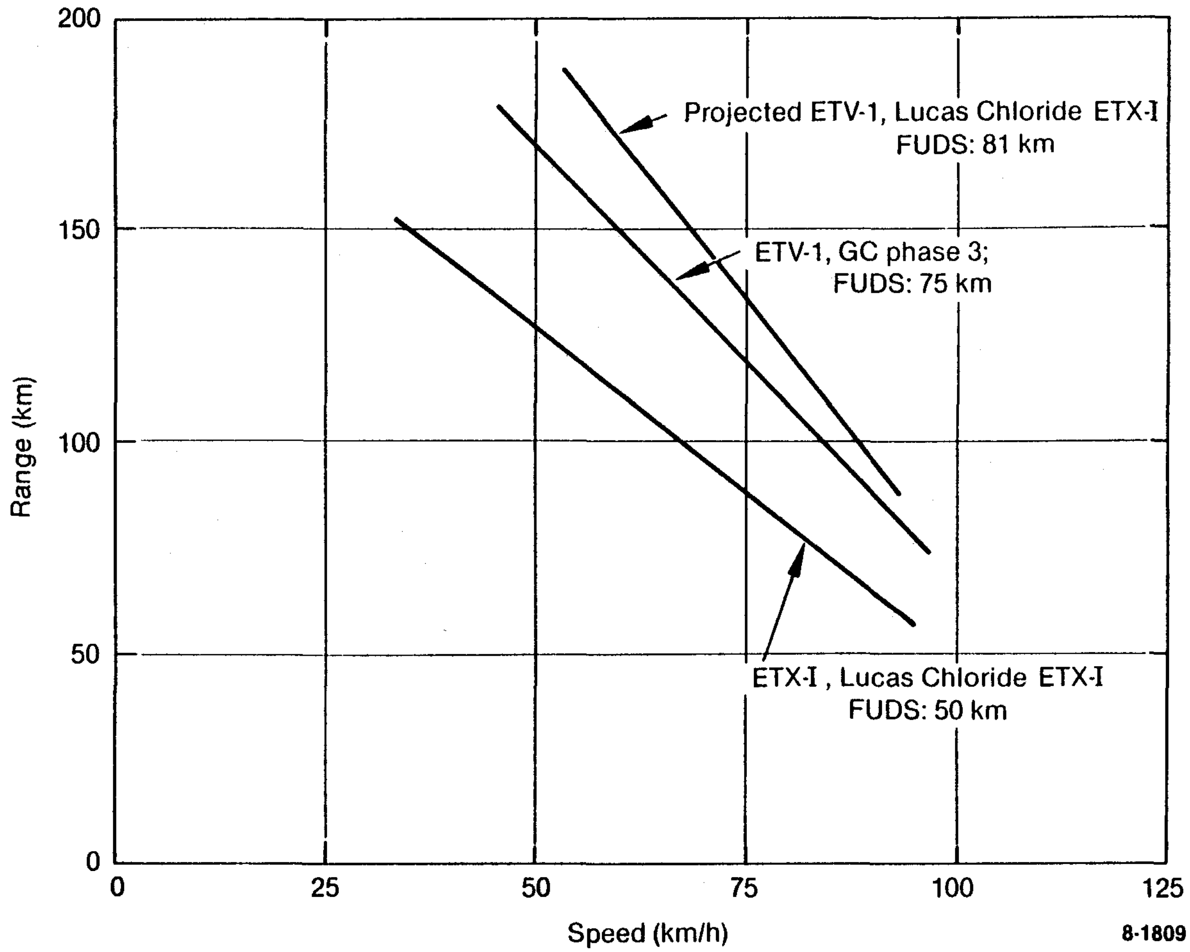

Figure 35. Range comparisons using the ETX-I and phase 3, Gel/Cell batteries in the ETX-I and ETV-1 vehicles.

Figure 36 indicates that the powertrain system efficiency for the ETV-1 is greater than that for the ETX-I for all the vehicle speeds. The primary reason for this is the significantly lower efficiency of the transmission in the ETX-I. The motor in the ETX-I is more efficient at all speeds than in the ETV-1, but the the difference is not large enough to overcome the lower efficiency of the transmission. This explains the higher energy consumption of the ETX-I compared to that of the ETV-1.

At the present time, the primary advantages of the ETX-I single shaft, integrated ac propulsion system for small, electric passenger cars are its small size and weight and projected lower cost. Additional improvement in powertrain efficiency, especially in the transmission at the light loads frequently encountered on most electric vehicle driving schedules, is needed before the ETX-I type ac powertrain will yield vehicle ranges comparable to those achieved using the ETV-2 dc powertrain.

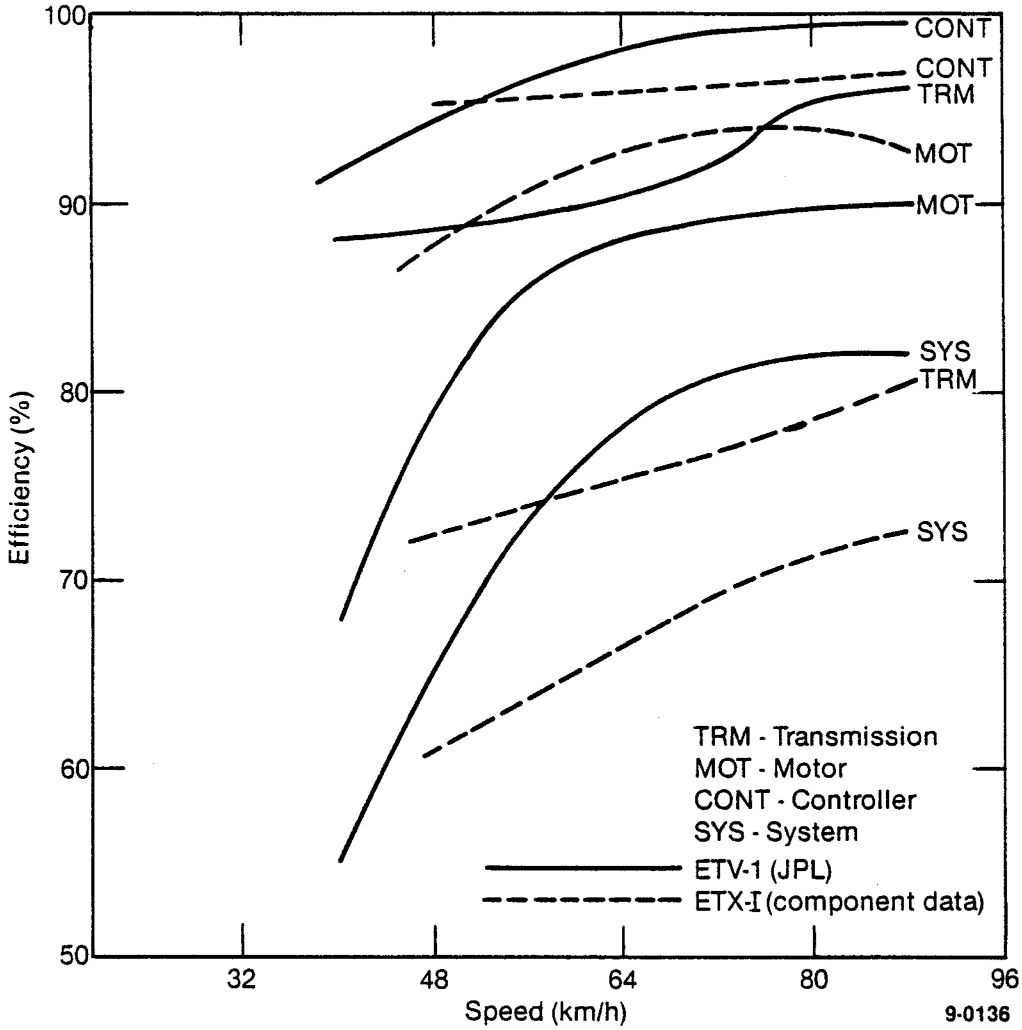

Figure 36. Comparison of ETX-I and ETV-1 component and system efficiencies.

8.0 CONCLUSIONS

Based on the test results discussed in the previous sections, the following conclusions concerning the ETX-I test vehicle and the ETX-I tubular lead-acid battery can be drawn:

1. The driveability of the ETX-I vehicle was excellent for all the constant speeds and driving cycles for which it was tested on the dynamometer; except for an occasional electronic shut down, the vehicle operated reliably and predictably during the test program.

2. The capacity of the Lucas Chloride tubular plate battery, as delivered to the INEL, was 91 Ah; which is about 9% less than the rated value. The capacity decreased by 10 to 15% during the dynamometer test program (75 cycles). The batteries have been shipped back to Lucas Chloride for postmortem inspection in an attempt to determine the reason for the capacity degradation.

3. The battery management system developed for the ETX-I battery functioned reasonably well during the tests, except for the equalization charge software that did not reliably provide a weekly equalization charge on Sunday if 400 Ah had been used from the battery in the previous week. Equalization charges occurred, but not on the predictable basis expected. The battery dc-dc charging efficiency was 60 to 70% for regular charges.

4. The energy consumption of the ETX-I at constant speed varied from 128 Wh/km at 40 km/h to 161 Wh/km at 88 km/h. For the FUDS cycle, the energy consumption was 208 Wh/km. The energy consumption of the ETX-I was 15 to 25% higher than that of the ETV-1 for the same driving conditions with the largest differences occurring for constant speed driving.

5. The range of the ETX-I, at constant speed varied from 128 km at 40 km/h to 67 km at 88 km/h. For the FUDS cycle, the range was about 60 km.

6. The energy density of the ETX-I batteries are 15-20% better than those of the Phase 3 Gel/cell batteries, at comparable discharge rates (10 to 20 W/kg). Use of the ETX-I battery in the ETV-1 (in place of the Phase 3 Gel/cells) would thus increase the range by about 15%.

7. The ETX-I battery has a higher internal resistance, especially at low states-of-charge, than the Gel/cell batteries. This characteristic of the tubular plate battery makes its capacity more sensitive to discharge rate and peak power than the Gel/cell batteries and precludes the use of all of its additional capacity on typical electric vehicle driving schedules.

8. The acceleration times of the ETX-I were 7.4 s for 0-48 km/h and 21.3 s for 0 to 80 km/h. These acceleration times are better than any other electric vehicle tested at the INEL, including the ETV-1.

9. The use of the single-shaft, ac powertrain in an electric vehicle has significant advantages, from the packaging point-of view because of its small size and weight. The acceleration performance of the ac powertrain is excellent, but improvements in powertrain efficiency at low speeds and light loads are needed before the ac powered vehicle will have comparable energy consumption and range to ETV-1 dc vehicle.

9. REFERENCES

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7. A. F. Burke, R. L. Crumley, J. E. Hardin, Phase 3 Gel/cell Battery Performance Tests and Comparisons with Other Lead-Acid Batteries, EGG-EP-7512, 1987

8. D. W. Kurtz, The DOE ETV-1 Electric Test Vehicle Phase III Final Report Performance Testing and System Evaluation, DOE/CS54209-3, December 1981

APPENDIX A

DYNAMOMETER INSTRUMENTATION LIST

TABLE A-1. Instrumentation List

Measurement	Symbol	Range	Accuracy	Response Time (s)	Upper Cut-Off Frequency (Hz)	Sensor Location	Output to Computer	Computer Input	Description
Battery Temperature	TBAT1	0-100	±1C°	1	0.5 (Computer)	Battery Module	0-9.708 MVMV Analog	+10 MV Analog	24-30 gauge ungrounded TC, ice point reference junction (Type E)
Battery Temperature	TBAT2	0-150	±1C°	1	0.5 (Computer)	Battery Module	0-9.708 MVMV Analog	+10 MV Analog	24-30 gauge ungrounded TC, ice point reference junction (Type E)
Battery Temperature	TBAT3	0-150	±1C°	1	0.5 (Computer)	Battery Module	0-9.708 MVMV Analog	+10 MV Analog	24-30 gauge ungrounded TC, ice point reference junction (Type E)
Battery Temperature	TBAT4	0-150	±1C°	1	0.5 (Computer)	Battery Module	0-9.708 MVMV Analog	+10 MV Analog	24-30 gauge ungrounded TC, ice point reference junction (Type E)
Electric Motor Temperature	TEM1	0-100	±1C°	1	0.5 (Computer)	Electric Motor	0-9.708 MVMV Analog	+10 MV Analog	24-30 gauge ungrounded TC, ice point reference junction (Type E)
Transaxle Temperature	TRCS	0-100	±1C°	1	0.5 (Computer)	Transmission	0-9.708 MVMV Analog	+10 MV Analog	24-30 gauge ungrounded TC, ice point reference junction (Type E)
Ambient Temperature	TAMB	0-100	±1C°	1	0.5 (Computer)	Dyno Room	0-9.708 MVMV Analog	+10 MV Analog	24-30 gauge ungrounded TC, ice point reference junction (Type E)
Battery Voltage	BV	0-300V	±1/2% FS	--	5 (PMI Box)	Vehicle	+10V FS	+10.24 V Analog	JPL PMI Box Card #1
Motor Phase A, B, C Voltage	MVA MVB MVC	0-100V	±1/2% FS	--	5 (PMI Box)	Vehicle	+10V FS	+10.24 V Analog	JPL PMI Box Card #3
Battery Amps	BA	0-500A	±1/2% FS	--	5 (PMI Box)	Vehicle	+10V FS	+10.24 V Analog	500 Amp shunt, JPL PMI Box Card #1
Motor Phase A, B, C Amperage	MAA MAB MAC	0-500A	±1/2% FS	--	5 (PMI Box)	Vehicle	+10V FS	+10.24 V Analog	500 Amp Shunt, JPL PMI Box Card #3
Dyno Torque	DT	0-3580 n	±1/2% FS	--	5 (Computer)	Dyno	0-10V FS	+10.24 V Analog	Daytronics Power Supply and Signal Conditioning
Dyno Idle Roll	DIR	0-3000 rpm	±0.5 rpm	--	--	Dyno	0-25 kHz	Pulse Accumulator	Digital Encoder
Dyno Load Roll	LDSPD	0-150 km/h	±0.161 km/h	--	5 (Computer)	Dyno	0-6.43 V @96.56 km/h	+10.24 V Analog	Clayton System Controller

TABLE A-1. (Continued)

Measurement	Symbol	Range	Accuracy	Response Time	Upper Cut-Off Frequency	Sensor Location	Output to Computer	Computer Input	Description
Accessory Battery Voltage	AUXBV	0 - 20 V	--	--	5 Hz (PMI)	Vehicle	+10VFS		JPL PMI: CARD 5
Accessory Battery Current	AUXBI	0 - 50 A	--	--	5 Hz (PMI)	Vehicle	+10VFS		JPL PMI: CARD 5
Energy Out Of Battery	EBOD PBOD	0 - 50 kWh 0 - 150 kWh	±0.5 kWh ±1.6 kWh	--	50 kHz (PMI Box)	Vehicle	0 - 10 kHz Digital	Pulse Accumulator	500-A Shunt, JPL PMI Card #1
Energy Into Battery pulse count	EBI PBI	0 - 50 kWh 0 - 90 kWh	±1/2 kWh ±1.6 kW	--	50 kHz (PMI Box)	Vehicle	0 - 10 kHz Digital	Pulse Accumulator	500-A Shunt, JPL PMI Card #1, Energy is a function of total
Power/Energy Into Motor	EMIA PMIA EMIB PMIB EMIC PMIC	0 - 50 kWh 0 - 50 kWh	±1/2% FS	--	50 kHz (PMI Box)	Vehicle	0 - 10 kHz Digital	Pulse Accumulator	500-A Shunt, JPL PMI Card #3 Energy is a function of total pulse count.
Total Ah out Battery	ABO	0 - 500 kAh	±1/2 FS	--	50 kHz (PMI Box)	Vehicle	0 - 10 kHz Digital	Pulse Accumulator	500-A Shunt, JPL PMI Card #2, Voltage input set at 10 V. Charge is a function of total pulse count.
Total Ah into Battery (Regenerative)	ABI	0 - 500 kAh	±1/2 FS	--	50 kHz (PMI Box)	Vehicle	0 - 10 kHz Digital	Pulse Accumulator	500-A Shunt, JPL PMI Card #2, Voltage input set at 10v. Charge is function of total pulse count.
Power out of Battery calculated.	PBO	0 - 100 kW	±1/2% FS	--	50 kHz (PMI Box)	Vehicle	0 - 10 kHz Digital	Pulse Accumulator	500-A shunt, JPL PMI Card #1. Average power is software
Power Into Battery software	PBI	0 - 100 kW	±1/2% FS	--	50 kHz (PMI Box)	Vehicle	0 - 10 kHz Digital	Pulse Accumulator	500-A shunt, JPL PMI Card #1. Average power is calculated.
Energy/Power out of Motor	EMOA PMOA EMOB PMOB EMOC PMOC	0 - 50 kWh 0 - 150 kW	±5% FS	--	10 kHz (PMI Box)	Vehicle	0 - 10 kHz Digital	Pulse Accumulator	500-A Shunt, JPL PMI Card #3 Average power is software calculated.

TABLE A-1 (Continued)

Measurement	Symbol	Range	Accuracy	Response Time	Upper Cut-Off Frequency	Sensor Location	Output to Computer	Computer Input	Description
Energy out of Accessory Battery	EAUXB	0 - 10 kW	±1/2% FS	--	50 kHz (PMI Box)	Vehicle	0 - 10 kHz Digital	--	50-A shunt, JPL PMI Card #5. Energy Function of total pulse.
Power out of Accessory Battery calculated.	PAUXB	0 - 1 kW	±1/2% FS	--	50 kHz (PMI Box)	Vehicle	0 - 10 kHz Digital	--	50-A shunt, JPL PMI Card #5. Average power software
Distance	DIST	0 - 322 km	±1/2% FS	--	--	Idle Roll	5-V pulse	Pulse Accumulator	Digital encoder
Cycles Driven	--	--	--	--	--	--	--	--	Computer calculated
Elapsed Time	--	--	--	--	--	--	--	--	Computer generated
kph	--	--	--	--	--	--	--	--	Computer calculated
Battery Recharge Amps	BAR	0 - 50A	±1/2% FS	--	5 kHz	Vehicle	+10 VFS	--	JPL PMI Card
Battery Recharge Energy	EBIR	0 - 500 kWh	±1/2% FS	--	50 kHz	Vehicle	0 - 10 kHz	--	JPL PMI Card
Battery Recharge Power	PBIR	0 - 15 kW	±1/2% FS	--	--	Vehicle	5-V Pulses	--	JPL PMI Card
Battery Recharge Ah	ABIR	0 - 500 Ah	±5.6 Ah	--	50 kHz	Vehicle	0 - 10kHz 5-V Pulses	--	JPL PMI Card
Energy Battery Recharge (ac wall power)	EBCI	0 - 500 Ah	TBD	--	50 kHz	Charger	0 - 6829 Hz 5-V PUlses	--	JPL PMI Card
Battery Recharge	BVR	0 - 300V	±2.5 V	--	5 Hz	Vehicle	+10V dc	--	JPL PMI Card

APPENDIX B
DYNAMOMETER COASTDOWN METHODS

ROAD LOAD FORCE RELATIONS

Laboratory vehicle performance testing utilizing a chassis dynamometer requires that the dynamometer be set up to accurately reproduce the road load characteristics of the vehicle obtained from track coastdown tests. A computerized method of analyzing road coastdown data and extracting the rolling resistance and aerodynamic drag coefficients to be used for matching the road load to the dynamometer load on vehicles has been developed at the INEL.[a] The INEL technique uses a least-squares parameter estimation technique to determine the rolling resistance and aerodynamic drag coefficients from velocity versus time data taken during the track coastdown. The technique also normalizes the data to standard conditions and compensates for track elevation variations.

The simplified force equation describing the coastdown motion (assuming no wind, grade, or aerodynamic lift) is given by

$$\text{Force} = M \frac{dV}{dt} = -C_{RR} W - \frac{1}{2} A{*}C_D{*}\rho V^2 = -(C_0 + C_1 V) W - \frac{1}{2} A{*}C_D{*}\rho V^2 \qquad \text{(A-1)}$$

where

M	=	effective vehicle mass (includes rotating mass)
C_{RR}	=	tire rolling resistance
W	=	vehicle weight
A	=	vehicle frontal area
C_D	=	aerodynamic drag coefficient
V	=	vehicle speed
ρ	=	air density.

Values for C_0, C_1, and C_D can be determined from the track coastdown data using a least-squares fitting technique. The vehicle mass, air density, and vehicle frontal area are determined separately and are input data to the estimation program.

Experience has shown that the fitting process converges most rapidly and reliably if C_1 is set equal to zero. This is not necessary, but otherwise one can experience an interaction between C_1 and C_D, which results in an unrealistically low value for C_D.

In Equation (A-1), the rolling resistance C_{RR} W is broken into two parts, namely C_0W and C_1VW where C_0W is the frictional force independent of velocity and C_1VW is the frictional force dependent on velocity. The aerodynamic force is given by 1/2 CD*A*ρ V2. Once the coefficients are determined, the rolling resistance horsepower and the aerodynamic horsepower are easily evaluated at any desired velocity and environmental condition.

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a. Techniques to Analyze Vehicle Coastdown Data by J. R. Venhuizen, EGG-ED-6725, April 1985

DYNAMOMETER ROAD LOAD MATCHING

At the INEL, a twin roll Clayton Model DC-80 chassis dynamometer is used for vehicle testing. The dynamometer consists of several components including a fixed "trim" flywheel and a number of declutchable rotating disks which allow the operator to set a rotational inertia equivalent to the linear inertia of a test vehicle to within 56.7 kg (125 lb). The power absorption unit is a direct current motor capable of providing a wide range of motoring or absorbing torques at various speeds. The microprocessor controlled system controller has the capability of electrically compensating the rotational inertia to match the exact weight of the test vehicle and to set up the dc-80 system to simulate the road load of the vehicle by inputting the rolling resistance and aerodynamic coefficients from the computer terminal.

To perform the vehicle road load simulation, the dynamometer is designed to solve the force equation and is written

$$F = A + BV + CV^n \qquad \text{(A-2)}$$

where

F = force at the surface of the rolls
V = velocity at the surface of the rolls
A = tire frictional force coefficient independent of velocity
B = tire frictional force dependent on velocity
C = windage(aerodynamic) force coefficient of velocity
n = velocity exponent (adjustable from 1.0 to 3.0).

This form of the equation has combined the constants from the coastdown analysis with the input constants

A = C0 W
B = C1 W
C = C_D (1/2 Aρ).

SET UP STEPS

This procedure uses a similar technique to that used to calculate the vehicle road loads during coastdown testing. It is based on the assumption that the velocity/time profile desired for coastdown of the vehicle mounted on the dynamometer is known. The coastdown program used to calculate the vehicle loads on the dynamometer is the same program used to calculate the road loads on the track.

Step 1

Remove vehicle half axles and disk brakes

Step 2

Warm-up the dyno and vehicle for 30 min at 80 km/h (50 mph). The A, B, and C coefficients in the force equation are set equal zero during warmup. The road load horsepower required to maintain 80 km/h (50 mph) is recorded(this is the roll and tire friction).

Step 3

The aerodynamic drag coefficient (C_D) from the road coastdown is set into the force equation ($C=C_D$) along with the exponential velocity value of 2.0.

Step 4

The vehicle is coasted down from 96 to 16 km/h (60 to 10 mph) with the velocity/time data being recorded on the laboratory data acquisition system.

Step 5

Data from Step 4 is analyzed to get the "effective" vehicle road load on the dyno. This procedure yields the effective coefficients in the following equation:

$$F = (A_D - A_E) + (B_D - B_E)\ V + C_D\ V^2$$

where the subscript D represents the desired coefficient and the subscript E the effective coefficient. The difference between the desired and effective coefficients becomes the settings for the dynamometer

$$A = AD - AE$$

$$B = BD - BE$$

$$C = CD = 1/2\ (C_D A)$$

Step 6

The coastdown is repeated with the dynamometer coefficients set equal to A, B, and C of Step 5.

(NOTE: Before each coastdown, the vehicle is warmed up to match the original friction load horsepower readings recorded in Step 2.)

Step 7

The difference between the new set of effective coefficients and the desired coefficients is added to the dyno coefficients and the process repeated. Usually three to four iterations are sufficient to determine the A and B coefficients such that the coastdown time from 96.5 to 16 km/h (60 to 10 mph), 88 to 72 km/h (55 to 45 mph), and 32 to 16 km/h (20 to 10 mph) match the track (target) coastdown times to within one second or less. If the systematic iterative procedure cited to determine A and B does not converge in 4 to 5 interations, a trial-and-error approach is used in which small changes are made in A, B, and C to affect final convergence to the desired accuracy in matching the coast-down curve.

The above matching technique results in a dynamometer coastdown curve for which the sum of squares of the differences in the velocities between the track and dynamometer curves is less than 1.00 using 100 to 150 time points in the coastdown.

APPENDIX C

BATTERY TEST DATA SUMMARY TABLES

TOTAL SUMMARY BATTERY DATA SHEET PACK NO. 29 (LCEVS)

	DISCHARGE								CHARGE								
INELCYCLES SUB.48CYC.	DATE	DR (A,P,F)	ABOD (Ah)	EBOD (KWH)	DCV* (VOLTS)	EDT (AVG.)	MAX.TEMP. (C)	TTD	DATE	ABIR (Ah)	EBIR (KWH)	CC (amps)	% CHARGE	ECT (AVG.)	MAX.TEMP. (°C)	TTOC	NOTES
LifeCycles		CYCLES 1 THRU 48 WERE DONE AT FORD BEFORE CAR WAS SHIPPED I.N.E.L.															
Cycle 1	11/14/85	C/3	95.0	17.70	---	73F	---	---									
Cycle 2	11/18/85	C/3	94.7	17.90	---	87F	---	---									
Cycle 3	11/27/85	C/2	89.7	16.70	---	85F	---	---									
Cycle 4	12/02/85	C/1	71.3	12.90	---	88F	---	---									
Cycle 5	12/04/85	C/.5	64.2	11.15	---	95F	---	---	CYCLES 1 THRU 48 DONE AT FORD, NO CHARGE DATA AVAILABLE.								
Cycle 6	12/05/85	C/5	101.9	19.40	---	84F	---	---									
Cycle 7	12/11/85	E-1	99.3	18.72	---	90F	---	---									
Cycle 8	12/12/85	FUDS	88.2	15.61	---	97F	---	---									
Cycle 9	01/06/86	FUDS	81.5	14.53	---	102F	---	---									
Cycle 10	01/09/86	C/2	----	----	---	96F	---	---									PACK WATERED,TOP-2 GAL.,BOTTOM-2.5 GAL.
Cycle 11	01/15/86	C/2	86.6	16.03	---	89F	---	---									
Cycle 12	01/16/86	C/1	77.9	14.10	---	104F	---	---									
Cycle 13	01/17/86	C/.5	58.9	10.19	---	97F	---	---									
Cycle 14	01/20/86	C/3	85.5	15.89	---	74F	---	---									
Cycle 15	01/23/86	C/3	91.8	16.93	---	78F	---	---									
Cycle 16	01/24/86	E-1	98.2	18.34	---	94F	---	---									
Cycle 17	01/27/86	C/1	72.8	13.10	---	93F	---	---									
Cycle 18	01/29/86	FUDS	79.1	14.10	---	98F	---	---									
Cycle 19	02/03/86	C/5	105.9	20.01	---	86F	---	---									
Cycle 20	02/04/86	FUDS	80.7	13.92	---	103F	---	---									
Cycle 21	02/05/86	FUDS	79.3	14.29	---	100F	---	---									PACK WATERED,TOP-3/8 GAL.,BOTTOM-5/8 GAL.
Cycle 22	02/06/86	FUDS	80.8	13.96	---	104F	---	---									
Cycle 23	02/10/86	C/3	93.2	17.41	---	---	---	---									
Cycle 24	02/11/86	C/2	88.2	16.36	---	89F	---	---									
Cycle 25	02/13/86	VEH FUDS	74.9	15.34	---	85F	---	---									
Cycle 26	02/14/86	VEH FUDS	74.6	15.87	---	94F	---	---									
Cycle 27	02/21/86	FUDS	79.5	14.76	---	92F	---	---									
Cycle 28	02/24/86	C/1	74.3	13.37	---	92F	---	---									
Cycle 29	02/26/86	FUDS	79.1	14.14	---	92F	---	---									
Cycle 30	03/10/86	E-1	----	----	---	---	---	---									PACK WATERED,TOP-1/4 GAL.,BOTTOM-1/2 GAL.
Cycle 31	03/11/86	C/2	93.3	17.35	---	92F	---	---									
Cycle 32	03/13/86	C/2	90.0	16.63	---	92F	---	---									
Cycle 33	03/17/86	E-1	93.5	16.93	---	88F	---	---									
Cycle 34	03/20/86	C/2	90.5	16.42	---	86F	---	---									
Cycle 35	03/24/86	FUDS	86.9	14.97	---	93F	---	---									
Cycle 36	03/25/86	C/1	75.0	13.67	---	97F	---	---									
Cycle 37	03/26/86	C/1	78.1	14.05	---	104F	---	---									
Cycle 38	06/09/86	VEH FUDS	59.9	12.20	---	---	---	---									
Cycle 39	06/10/86	VEH FUDS	70.1	14.40	---	---	---	---									
Cycle 40	06/12/86	VEH FUDS	69.8	14.30	---	---	---	---									
Cycle 41	06/25/86	VEH FUDS	----	----	---	---	---	---									
Cycle 42	06/27/86	VEH FUDS	42.8	9.00	---	---	---	---									
Cycle 43	09/03/86	VEH FUDS	78.9	14.50	---	---	---	---									
Cycle 44	09/04/86	FUDS	87.8	15.50	---	---	---	---									
Cycle 45	09/05/86	C/3	107.0	20.60	---	---	---	---									
Cycle 46	09/08/86	FUDS	69.7	12.20	---	---	---	---									

TOTAL SUMMARY BATTERY DATA SHEET PACK NO. 29 (LCEVS)

	DISCHARGE								CHARGE								
INELCYCLES SUB.48CYC.	DATE	DR (A,P,F)	ABOD (Ah)	EBOD (KWH)	DCV* (VOLTS)	EDT (AVG.)	MAX.TEMP. (C)	TTD	DATE	ABIR (Ah)	EBIR (KWH)	CC (amps)	% CHARGE	ECT (AVG.)	MAX.TEMP. (°C)	TTOC	NOTES
Cycle 47	10/03/86	C/1	63.5	11.10	---	---	---	---									
Cycle 48	10/08/86	C/1	60.4	10.50	---	---	---	---									
Cycle 49	05/28/87	32	68.11	12.55	160.0	26.6	27.0	2H 08M	05/28/87	115.93	25.76	8.90	170	41.3	42.4	9H 58M	WATERED PACK 5/27/87, BEFORE DISCHARGE # 1
Cycle 50	06/01/87	32	87.29	16.19	160.0	28.8	29.5	2H 47M	06/01/87	112.86	24.74	8.29	129	35.5	36.2	9H 20M	TOP TIER 5 LITERS, BOTTOM TIER, 10 LITERS
Cycle 51	06/02/87	32	90.56	16.88	160.0	27.5	28.0	2H 53M	06/02/87	109.36	23.77	8.42	120	39.8	40.5	8H 35M	
Cycle 52	06/03/87	32	91.61	17.07	160.0	27.6	28.4	3H 01M	06/03/87	112.45	24.44	8.47	123	40.9	41.9	8H 50M	
Cycle 53	06/04/87	45	83.76	15.47	158.0	28.9	29.8	1H 55M	06/04/87	99.76	21.73	8.04	119	35.6	36.9	7H 52M	
Cycle 54	06/05/87	45	83.01	15.31	158.0	27.8	28.6	1H 51M	06/05/87	100.96	22.12	8.20	122	36.1	37.9	8H 05M	
Cycle 55	06/08/87	45	81.19	14.99	158.0	28.6	28.9	1H 50M	06/08/87	96.27	21.06	7.80	118	34.9	36.2	7H 45M	
Cycle 56	06/09/87	74	71.46	12.87	152.0	31.3	32.1	1H 00M	06/09/87	87.83	19.46	7.73	122	32.8	34.0	7H 20M	
Cycle 57	06/10/87	74	70.55	12.73	152.0	31.2	31.9	59M	06/10/87	----	----	----	----	31.6	32.8	7H 30M	
Cycle 58	06/11/87	74	72.66	12.72	152.0	30.4	31.3	59M	06/11/87	90.73	20.19	8.79	124	34.3	35.6	7H 15M	
Cycle 59	06/12/87	32	92.12	17.23	160.0	28.2	28.7	2H 55M	06/12/87	114.19	25.22	8.50	123	37.9	38.7	9H 00M	
Cycle 60	06/15/87	32	87.43	16.35	160.0	25.7	26.4	2H 49M	06/15/87	112.45	24.86	9.40	129	38.4	39.8	8H 46M	WATERED PACK, AFTER CYCLE 13 CHARGE
Cycle 61	06/16/87	32	91.27	17.14	160.0	28.0	28.7	2H 57M	06/16/87	119.38	26.37	9.18	130	40.1	41.7	9H 10M	TOP TIER, 3 LITERS, BOTTOM TIER, 4 LITERS
Cycle 62	06/17/87	7W/KG	50.80	9.96	190.0	24.4	24.7	3H 00M	06/17/87	70.92	16.00	9.03	140	35.8	36.6	6H 00M	CYCLE 14 DIS. ABORTED EARLY, WRONG NUMBERS USED IN PROG.
Cycle 63	06/18/87	7W/KG	101.44	19.14	162.0	25.9	26.5	4H 28M	06/18/87	118.20	26.01	8.30	117	36.5	38.1	9H 25M	
Cycle 64	06/19/87	7W/KG	98.16	18.53	162.0	25.3	26.1	4H 29M	06/19/87	121.02	26.67	8.79	123	36.9	38.4	9H 35M	
Cycle 65	06/22/87	21W/KG	73.20	13.16	151.0	30.6	31.4	1H 03M	06/22/87	88.00	19.62	6.64	120	30.6	32.4	8H 20M	
Cycle 66	06/23/87	21W/KG	70.66	12.77	151.0	29.4	30.3	1H 02M	06/23/87	85.01	18.93	7.57	120	31.1	32.2	7H 35M	
Cycle 67	06/24/87	42W/KG	52.50	8.85	138.0	32.9	33.4	22M	06/24/87	68.62	15.45	7.47	130	29.1	30.6	6H 10M	
Cycle 68	06/25/87	42W/KG	52.07	8.80	138.0	34.8	35.1	22.5M	06/25/87	64.90	14.63	6.30	124	28.6	29.8	6H 30M	
Cycle 69	06/26/87	ATTEMPTED	SFUDS79	NO DATA		----	----	----	06/26/87	21.37	4.97	8.06	---	29.9	30.4	2H 03M	ATTEMPTED TO RUN S FUDS 79 & EQUIPT. FAILED
Cycle 70	06/29/87	SFUDS79	45.00	7.66	133.0	----	----	1H 54M	06/29/87	58.56	13.16	7.62	130	30.0	31.2	5H 09M	
Cycle 71	06/30/87	SFUDS79	42.00	7.26	133.0	30.0	31.8	1H 48M	06/30/87	54.97	12.34	6.77	130	32.0	33.0	5H 18M	PACK WATERED, TOP TIER-3 LITERS, BOTTOM TIER-4.5 LITERS
	EST. RANGE OF 1 DSEP VEHICLE ON SFUDS79 IS 41.2 kilometers (25.75 MI.)																
Cycle 72	07/01/87	60W/KG	40.20	6.30	124.0	34.0	34.7	11M	07/01/87	50.70	11.36	7.04	126	30.0	30.8	4H 35M	PACK RETURNED TO IRC LAB. C13 ON 7/02/87
Cycle 73	07/30/87	45.51	65.83	11.92	133.0	35.2	----	1H 27M	07/30/87	100.67	22.39	7.50	153	47.7	----	5h 25m	
Cycle 74	07/31/87	45.37	78.31	13.61	133.0	39.0	----	1H 44M	07/31/87	106.02	23.68	7.62	135	49.0	----	6H 55M	
Cycle 75	08/03/87	32.17	87.04	15.87	156.6	28.4	----	2H 39M	08/03/87	134.03	30.14	7.68	154	44.4	----	9H 35M	
Cycle 76	08/04/87	32.74	91.66	16.84	159.3	26.7	----	2H 48M	08/04/87	113.98	25.40	7.48	124	41.0	----	6H 30M	
Cycle 77	08/06/87	48KM/HR	90.57	16.62	159.0	29.3	----	2H 47M	08/06/87	111.86	25.34	7.48	124	27.2	----	6H 35M	
Cycle 78	08/11/87	DCYCLE	68.35	11.93	132.4	33.0	----	1H 17M	08/11/87	115.67	26.29	7.60	169	44.9	----	9H	
Cycle 79	08/18/87	CCYCLE	72.89	12.69	132.7	31.6	----	2H 26M	08/18/87	93.73	20.95	7.58	129	34.1	----	5H 45M	
Cycle 80	08/20/87	64KM/HR	72.99	13.30	158.4	30.1	----	1H 35M	08/20/87	120.83	27.61	7.58	166	40.1	----	9H 15M	AN EQUALIZATION CHARGE WAS PERFORMED
Cycle 81	08/21/87	88KM/HR	61.84	11.08	159.9	31.0	----	49M	08/21/87	103.66	23.58	7.58	168	43.2	----	7H 55M	
Cycle 82	08/24/87	ACCEL	76.56	13.50	132.7	28.9	----	2H 14M	08/24/87	94.59	20.72	8.18	124	38.9	----	7H 50M	
Cycle 83	08/26/87	EEC	87.17	15.70	159.5	28.9	----	2H 27M	08/26/87	109.59	24.55	7.58	126	39.3	----	6H 28M	
Cycle 84	08/28/87	ABORTED	51.15	9.12	---	---	----	1H 01M	08/28/87	88.56	20.34	7.63	173	46.5	----	6H 55M	
Cycle 85	08/31/87	DCYCLE	67.00	11.31	133.1	33.5	----	1H 19M	08/31/87	83.94	18.79	7.62	125	43.0	----	4H 40M	
Cycle 86	09/01/87	FUDS	77.52	13.16	129.8	33.3	----	2H 51M	09/01/87	101.34	22.80	7.55	131	36.2	----	6H	
Cycle 87	09/02/87	SIMFUDS	73.65	12.53	132.8	32.2	----	2H 55M	09/02/87	94.38	21.30	7.35	128	36.5	----	5H 45M	
Cycle 88	09/03/87	NONCONT	68.84	11.65	133.2	34.1	----	1H 23M	09/03/87	112.96	25.68	7.60	164	46.6	----	8H 25M	AN EQUALIZATION CHARGE WAS PERFORMED
Cycle 89	09/09/87	DCYCLE	59.80	10.12	132.8	32.6	----	1H 15M	09/09/87	83.03	19.04	7.55	139	35.1	----	5H 25M	
Cycle 90	09/10/87	48KM/HR	86.60	15.78	159.5	27.9	----	2H 47M	09/10/87	108.57	24.51	7.55	125	34.9	----	6H 25M	
Cycle 91	09/11/87	CCYCLE	81.87	13.95	132.2	30.0	----	4H 49M	09/11/87	129.30	29.51	7.55	158	35.9	----	9H 35M	AN EQUALIZATION CHARGE WAS PERFORMED
Cycle 92	10/09/87	C3DISCHAR	88.80	-----	160.0	-----	----	2H 47M	10/09/87	112.79	24.92	7.48	127	45.4	----	6H 30M	

TOTAL SUMMARY BATTERY DATA SHEET PACK NO. 29 (LCEVS)

INELCYCLES SUB.48CYC.	DISCHARGE DATE	DR (A,P,F)	ABDD (Ah)	EBDD (KWH)	DCV* (VOLTS)	EDT (AVG.)	MAX.TEMP. (C)	TTD	CHARGE DATE	ABIR (Ah)	EBIR (KWH)	CC (amps)	% CHARGE	ECI (AVG.)	MAX.TEMP. (°C)	TTOC	NOTES
Cycle 93	10/12/87	48KM/HR	91.44	16.09	-----	-----	----	2H 47M	10/12/87	135.57	30.71	7.58	148	41.0	----	9H 50M	ABORTED TEST EQUALIZATION CHARGE PERFORMED
Cycle 94	10/13/87	88KM/HR	59.28	10.64	160.0	32.7	----	53M	10/13/87	79.56	17.90	7.55	134	38.3	----	4H 45M	ABORTED TEST
Cycle 95	10/14/87	88KM/HR	60.70	10.75	-----	-----	----	51M	10/14/87	77.99	17.62	7.43	128	38.8	----	4H 40M	CHECKOUT RUN
Cycle 96	10/15/87	-----	50.56	9.73	-----	-----	----	---	10/15/87	69.48	15.79	7.53	137	36.7	----	4H 15M	ABORTED TEST
Cycle 97	10/20/87	-----	39.16	7.09	-----	-----	----	32M	10/20/87	61.57	14.03	7.40	157	37.4	----	4H 25M	ABORTED TEST
Cycle 98	10/23/87	88KM/HR	53.93	9.62	160.0	31.2	----	42M	10/23/87	92.47	21.08	7.48	171	48.5	----	7H 10M	EQUALIZATION CHARGE PERFORMED
Cycle 99	10/26/87	48KM/HR	85.59	15.65	160.0	30.2	----	2H 39M	10/26/87	104.68	23.40	7.40	122	38.7	----	6H 10M	
Cycle 100	10/27/87	CCYCLE	76.51	13.47	133.0	32.6	----	2H 35M	10/27/87	95.28	21.27	7.43	125	38.5	----	5H 45M	
Cycle 101	10/28/87	ACCEL	82.63	14.69	160.0	33.9	----	2H 17M	10/28/87	128.47	29.00	7.35	155	41.6	----	9H 35M	EQUALIZATION CHARGE PERFORMED
Cycle 102	10/29/87	FEC	93.45	16.72	160.0	31.8	----	2H 37M	10/29/87	113.55	25.24	7.45	122	40.1	----	6H 35M	
Cycle 103	10/30/87	64KM/HR	82.29	14.81	160.0	31.7	----	1H 47M	10/30/87	104.42	23.33	7.43	127	39.7	----	6H 15M	
Cycle 104	11/02/87	DCYCLE	65.12	11.02	133.0	31.7	----	1H 16M	11/02/87	85.46	19.22	7.55	131	38.2	----	5H 15M	
Cycle 105	11/03/87	CCYCLE	80.89	14.09	133.0	32.3	----	2H 36M	11/03/87	101.06	22.61	7.55	125	38.5	----	6H 5M	
Cycle 106	11/20/87	----	61.18	10.30	160.0	25.9	----	1H 30M	11/20/87	93.34	20.68	8.35	153	38.7	----	7H 45M	VEHICLE TROUBLE SHOOTING SPEIGAL CHARGER USED
Cycle 107	11/24/87	DCYCLE	60.72	10.17	133.0	33.1	----	2H 13M	11/24/87	104.61	23.98	7.38	172	40.5	----	8H 20M	AN EQUALIZATION CHARGE WAS PERFORMED
Cycle 108	11/25/87	88KM/HR	59.61	10.60	160.0	26.9	----	45M	11/25/87	75.11	16.93	7.53	126	39.0	----	4H 20M	
Cycle 109	12/01/87	CCYCLE	63.99	11.13	133.0	28.7	----	2H 12M	12/01/87	82.63	18.70	7.38	129	37.4	----	5H 10M	
Cycle 110	12/02/87	DCYCLE	55.88	9.64	133.0	33.9	----	1H 08M	12/02/87	73.39	16.65	7.50	131	37.0	----	4H 30M	
Cycle 111	12/03/87	CCYCLE	71.32	12.54	133.0	31.9	----	2H 31M	12/03/87	90.24	20.12	7.43	127	39.4	----	5H 30M	
Cycle 112	12/04/87	CCYCLE	78.94	13.83	133.0	31.3	----	2H 26M	12/04/87	97.91	21.87	7.52	124	37.5	----	5H 50M	
Cycle 113	12/07/87	FUDS	69.16	11.45	133.0	29.2	----	2H 25M	12/07/87	115.18	26.16	7.53	167	41.0	----	9H 5M	AN EQUALIZATION CHARGE WAS PERFORMED
Cycle 114	12/08/87	DCYCLE	62.24	10.65	133.0	31.6	----	1H 08M	12/08/87	79.72	17.90	7.38	128	37.0	----	4H 45M	
Cycle 115	12/09/87	DCYCLE	65.75	10.85	133.0	31.7	----	2H 17M	12/09/87	82.59	18.58	7.50	126	35.2	----	5H 10M	
Cycle 116	12/10/87	FUDS	76.17	12.75	133.0	31.9	----	2H 48M	12/10/87	94.48	21.22	7.40	124	37.2	----	5H 45M	
Cycle 117	12/15/87	SIMFUDS	50.38	8.67	133.0	24.3	----	1H 42M	12/15/87	69.21	15.73	----	137	33.7	----	4H 40M	ABORTED TEST
Cycle 118	12/17/87	NO DATA TAKEN, VEHICLE CHECK OUT				----	----	----	12/17/87	89.65	20.01	----		39.3	----	5H 20M	VEHICLE CHECKOUT NO DISCHARGE DATA TAKEN
Cycle 119	12/18/87	SIMFUDS	70.56	11.76	133.0	33.2	----	2H 39M	12/18/87	113.65	25.85	7.38	161	42.8	----	8H 35M	AN EQUALIZATION CHARGE WAS PERFORMED
Cycle 120	12/21/87	CCYCLE	69.56	11.28	133.0	27.3	----	3H 46M	12/21/87	84.84	19.13	7.48	122	36.9	----	5H 10M	
Cycle 121	12/22/87	FUDS	72.12	12.34	133.0	33.3	----	2H 48M	12/22/87	92.76	20.74	7.50	129	38.9	----	5H 40M	
Cycle 122	12/23/87	DCYCLE	61.11	10.35	133.0	33.9	----	1H 16M	12/23/87	80.27	18.06	7.35	131	38.4	----	4H 50M	
Cycle 123	12/29/87	DCYCLE	82.16	15.37	160.0	29.0	29.4	2H 33M	12/29/87	90.56	20.03	6.40	110	35.3	37.0	8H 36M	PACK RETURNED TO BATT.LAB ON 12/29/87,& TOPPED OFF,7.5 AH
Cycle 124	12/30/87	DCYCLE	84.15	15.71	160.0	27.9	29.0	2H 44M	12/30/87	103.02	22.81	7.91	122	32.8	34.1	8H 26M	AVG. SP. GR. AFTER CHARGE 76 1.267
Cycle 125	12/31/87	32	85.96	16.06	160.0	27.4	28.3	2H 46M	12/31/87	105.03	23.26	8.59	122	26.4	34.3	8H 30M	PACK RETURNED TO DYNO. LAB.
Cycle 126	01/05/88	----	75.34	12.45	133.0	35.1	----	----	01/05/88	88.06	19.42	7.40	117	35.6	----	5H 42M	
Cycle 127	01/06/88	27.0	62.08	10.38	133.0	31.6	----	2H 18M	01/06/88	105.63	24.11	7.53	170	42.3	----	8H 15M	
Cycle 128	01/07/88	30.7	76.17	13.40	133.0	31.3	----	2H 29M	01/07/88	99.61	22.38	7.50	131	40.4	----	6H 05M	
Cycle 129	01/08/88	54.3	60.83	10.50	133.0	33.6	----	1H 07M	01/08/88	79.48	17.88	7.43	131	41.9	----	4H 35M	
Cycle 130	01/11/88	33.3	76.48	13.90	160.0	27.9	----	2H 18M	01/11/88	97.68	21.79	7.38	128	38.1	----	6H 00M	
Cycle 131	01/12/88	50.2	68.23	11.57	133.0	36.6	----	1H 23M	01/12/88	81.88	17.98	8.13	120	35.6	----	6H 40M	
Cycle 132	01/13/88	34.3	82.87	14.90	160.0	28.9	----	2H 25M	01/13/88	95.31	20.84	8.28	115	36.2	----	7H 46M	
Cycle 133	01/14/88	29.1	79.08	13.45	133.0	26.6	----	2H 43M	01/14/88	96.66	21.26	8.60	122	38.3	----	7H 55M	
Cycle 134	01/15/88	46.7	76.52	13.73	160.0	31.7	----	1H 39M	01/15/88	89.18	19.48	8.35	117	37.5	----	7H 10M	
Cycle 135	01/19/88	28.0	70.53	11.75	133.0	32.8	----	2H 31M	01/19/88	82.37	18.09	8.65	117	36.5	----	6H 45M	
Cycle 136	01/20/88	29.3	72.71	12.50	133.0	30.8	----	2H 30M	01/20/88	85.23	18.76	8.07	117	34.9	----	7H 05M	
Cycle 137	01/21/88	----	56.92	11.90	133.0	33.0	----	2H 26M	01/21/88	88.13	19.50	----	155	35.9	----	7H 35M	
Cycle 138	01/22/88	80.8	79.99	10.09	160.0	32.3	----	42M	01/22/88	69.05	15.35	----	86	31.3	----	6H 00M	
Cycle 139	01/26/88	32	79.99	14.82	160.0	29.6	30.2	2H 28M	01/26/88	100.13	22.06	7.68	125	35.3	36.7	8H 15M	WATERED PACK, AFTER CYCLE 90 CHARGE

TOTAL SUMMARY BATTERY DATA SHEET   PACK NO. 29 (LCEVS)

	DISCHARGE								CHARGE								
INELCYCLES SUB.48CYC.	DATE	DR (A,P,F)	ABOD (Ah)	EBOD (KWH)	DCV* (VOLTS)	EDT (AVG.)	MAX.TEMP. (C)	TTD	DATE	ABIR (Ah)	EBIR (KWH)	CC (amps)	% CHARGE	ECT (AVG.)	MAX.TEMP. (°C)	TTOC	NOTES
Cycle 140	01/28/88	32	80.39	14.94	160.0	27.0	27.9	2H 30M	01/28/88	96.29	21.16	8.23	120	35.2	36.5	7H 45M	TOP TIER, 2.5 LITERS, BOTTOM TIER, 3 LITERS
Cycle 141	01/29/88	32	80.62	15.03	160.0	28.3	29.3	2H 30M	01/29/88	102.53	22.65	7.92	127	33.9	36.4	8H 35M	
	02/03/88	EQUALIZATION CHARGE, CONSTANT CURRENT 4 AMPS, WITH SIMULATOR								113.86	27.14	3.71		33.9	35.7	27H 30M	AVG. SP. GR. 1.305
Cycle 142	02/05/88	32	84.52	15.81	160.0	29.4	30.0	2H 39M	02/05/88	106.63	23.62	8.23	126	33.5	37.6	8H 55M	
Cycle 143	02/08/88	32	81.62	15.30	160.0	27.4	28.3	2H 34M	02/08/88	104.57	22.77	4.06	128	29.0	30.7	24H 00M	CHARGE, CONSTANT CURRENT 4 AMPS, WITH SIMULATOR
Cycle 144	02/10/88	32	82.52	15.49	160.0	28.6	30.1	2H 36M	02/11/88	103.68	23.01	7.81	126	32.9	35.8	8H 45M	
Cycle 145	02/11/88	4.4	109.16	20.98	163.0	24.0	25.2	24H 40M	02/12/88	151.57	33.30	8.82	139	37.4	41.6	12H 05M	
Cycle 146	02/16/88	32	83.30	15.61	160.0	26.7	29.4	2H 39M	02/16/88	115.22	25.59	8.85	138	34.5	38.0	9H 25M	AVG. SP. GR. 1.315
Cycle 147	02/18/88	32	80.80	15.21	160.0	23.6	25.1	2H 33M	02/18/88	113.11	25.46	6.44	140	22.4	26.2	10H 50M	AVG. SP. GR. 1.314
		PACK RETURNED TO DYNO LAB. 2/19/88															PACK WATERED, TOP TIER-7.5L, BOTTOM TIER-8.5L
Cycle 148	02/19/88	27.2	76.38	13.00	133.0	30.5	----	2H 48M	02/19/88	90.51	19.77	8.98	118	38.1	----	7H 00M	FUD'S CYCLE
Cycle 149	02/22/88	34	85.49	15.82	160.0	27.0	----	2H 30M	02/22/88	101.45	22.14	8.70	118	35.9	----	8H 05M	48 KPH
Cycle 150	02/23/88	47.88	79.01	14.30	160.0	30.5	----	1H 39M	02/23/88	92.89	20.13	8.73	117	37.0	----	7H 30M	64 KPH
Cycle 151	02/24/88	47.13	78.24	14.32	160.0	29.6	----	1H 40M	02/24/88	96.27	21.45	7.33	123	25.1	----	8H 45M	64 KPH
Cycle 152	02/26/88	46.53	73.05	13.39	160.0	26.8	----	1H 34M	02/26/88	86.93	19.08	8.68	119	35.7	----	7H 05M	64 KPH
Cycle 153	03/31/88	46.13	65.50	11.88	160.0	27.1	----	1H 25M	03/31/88	100.72	22.79	7.78	154	26.8	----	9H 37M	
Cycle 154	03/22/88	DCYCLE	63.32	10.78	133.0	31.9	----	1H 16M	03/22/88	80.87	18.10	7.60	128	25.8	----	7H 15M	
Cycle 155	03/23/88	FUDS	74.10	12.75	133.0	31.0	----	2H 48M	03/23/88	93.64	20.93	7.63	126	26.6	----	8H 30M	
Cycle 156	03/24/88	48KM/HR	87.08	16.12	160.0	26.4	----	2H 40M	03/24/88	101.94	22.58	7.73	117	27.2	----	8H 45M	
Cycle 157	03/25/88	88 KM/HR	62.56	11.19	160.0	31.0	----	50M	03/25/88	77.06	16.93	8.83	123	37.3	----	6H 20M	
Cycle 158	03/28/88	FUDS	71.53	12.12	133.0	32.0	----	2H 35M	03/28/88	92.13	20.57	7.80	129	28.9	----	8H 15M	
Cycle 159	03/29/88	FUDS	70.85	12.15	133.0	32.3	----	2H 35M	03/29/88	90.96	20.34	7.70	128	26.8	----	8H 10M	
Cycle 160	03/30/88	ABORTED	68.11	12.44	160.0	28.0	----	----	03/30/88	86.70	19.28	7.40	127	25.2	----	7H 45M	
Cycle 161	03/31/88	72.4KM/HR	69.28	12.40	160.0	26.5	----	1H 11M	03/31/88	86.63	19.29	7.10	125	24.8	----	7H 55M	
Cycle 162	04/01/88	72.4KM/HR	69.78	12.40	160.0	28.2	----	1H 16M	04/01/88	81.72	17.81	8.28	117	33.3	----	6H 30M	
Cycle 163	04/04/88	DCYCLE	60.96	10.31	133.0	30.7	----	1H 14M	04/04/88	74.20	16.47	7.48	122	24.5	----	6H 30M	
Cycle 164	04/05/88	DCYCLE	60.86	10.38	133.0	30.2	----	1H 17M	04/05/88	84.00	18.90	7.00	138	24.3	----	8H 15M	
Cycle 165	04/06/88	ACC	76.77	13.74	160.0	28.5	----	2H 08M	04/06/88	94.90	21.09	7.10	124	24.0	----	8H 40M	
Cycle 166	04/07/88	ABORTED	74.57	12.84	133.0	30.9	----	2H 57M	04/07/88	83.15	18.32	7.10	112	22.2	----	7H 10M	
Cycle 167	04/08/88	FUDS	71.41	12.43	133.0	30.1	----	2H 49M	04/08/88	86.39	18.89	8.70	121	37.3	----	7H 5M	
Cycle 168	04/11/88	45MPH	67.20	12.25	160.0	28.6	----	1H 17M	04/11/88	80.13	17.19	6.53	119	21.9	----	7H 15M	
Cycle 169	04/12/88	DCYCLE	60.86	10.49	133.0	31.1	----	1H 19M	04/12/88	72.95	16.14	6.98	120	25.2	----	6H 30M	
Cycle 170	04/13/88	FUDS	70.49	12.39	133.0	32.7	----	2H 48M	04/13/88	82.63	18.26	7.48	117	27.2	----	7H 10M	
Cycle 171	04/14/88	ACC	76.37	13.77	160.0	29.9	----	2H 06M	04/14/88	89.45	19.70	7.65	117	27.8	----	7H 45M	
Cycle 172	04/15/88	88KM/HR	61.97	11.04	150.0	30.3	----	51M	04/15/88	79.10	17.44	8.93	128	35.6	----	6H 40M	
Cycle 173	04/18/88	88KM/HR	59.08	10.49	150.0	29.1	----	48M	04/18/88	69.57	15.47	7.25	118	24.6	----	6H 5M	
Cycle 174	04/20/88	DCYCLE	57.58	9.82	133.0	32.0	----	1H 13M	04/20/88	73.87	16.41	8.08	128	27.5	----	6H 15M	
Cycle 175	04/25/88	32	80.30	14.97	160.0	29.0	29.9	2H 30M	04/25/88	109.66	24.24	9.62	137	36.4	37.8	8H 05M	
Cycle 176	04/26/88	32	78.79	14.73	160.0	26.5	27.6	2H 36M	04/26/88	104.72	23.17	9.08	133	34.6	36.7	8H 05M	
Cycle 177	04/27/88	32	78.94	14.79	160.0	25.6	27.2	2H 33M	04/27/88	110.50	24.61	9.28	140	30.4	33.5	8H 20M	
Cycle 178	04/28/88	45	73.81	13.71	158.0	27.1	29.8	1H 36M	04/28/88	103.63	23.20	9.57	140	30.1	33.5	7H 45M	
Cycle 179	04/29/88	45	72.35	13.46	158.0	27.3	29.0	1H 36M	04/29/88	91.40	20.38	8.69	126	29.6	32.7	7H 25M	
Cycle 180	05/02/88	45	67.76	12.48	158.0	26.6	27.9	1H 30M	05/02/88	88.27	19.71	8.50	130	31.1	34.0	7H 25M	PACK WATERED, TOP TIER-6L, BOTTOM TIER-5L
Cycle 181	05/03/88	74	60.52	10.82	152	27.7	29.9	50M	05/03/88	81.46	18.25	8.50	134	31.0	33.9	6H 44M	
Cycle 182	05/04/88	74	60.48	10.83	152	28.2	30.6	50M	05/04/88	76.50	17.06	8.45	126	29.2	32.1	6H 10M	
Cycle 183	05/05/88	74	60.21	10.77	152	28.2	29.8	50M	05/05/88	75.94	16.97	8.69	126	29.7	32.4	6H 05M	
Cycle 184	05/06/88	32	80.15	14.89	160.0	25.3	26.5	2H 30M	05/06/88	97.31	21.55	8.45	121	31.0	33.9	7H 50M	

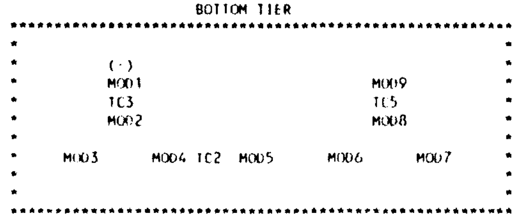
TOTAL SUMMARY BATTERY DATA SHEET PACK NO. 29 (LCEVS)

INELCYCLES SUB.48CYC.	DISCHARGE DATE	DR (A,P,F)	ABOD (Ah)	EBOD (KWH)	DCV* (VOLTS)	EDT (AVG.)	MAX.TEMP. (C)	TTD	CHARGE DATE	ABIR (Ah)	EBIR (KWH)	CC (amps)	% CHARGE	ECT (AVG.)	MAX.TEMP. (°C)	TTOC	NOTES
Cycle 185	05/09/88	32	83.91	15.62	160.0	26.7	28.3	2H 39M	05/09/88	101.83	22.54	9.08	121	30.8	33.8	8H 00M	
Cycle 186	05/10/88	32	80.62	15.05	160.0	25.3	27.3	2H 33M	05/10/88	105.79	23.52	8.74	131	32.2	35.1	8H 30M	
Cycle 187	05/11/88	7W/KG	89.01	16.78	162.0	24.0	25.9	4H 03M	05/11/88	112.52	24.92	9.23	126	33.2	35.5	8H 55M	PACK WATERED, TOP TIER-1L, BOTTOM TIER-1L
Cycle 188	05/12/88	7W/KG	90.83	17.30	162.0	27.0	27.4	4H 03M	05/12/88	113.91	25.07	9.28	125	36.8	38.9	8H 50M	
Cycle 189	05/17/88	21W/KG	62.01	11.05	151.0	29.4	31.0	50M	05/17/88	85.11	18.99	8.30	137	27.2	28.6	7H 35M	
Cycle 190	05/18/88	42W/KG	39.98	6.69	151.0	29.0	29.8	15M	05/18/88	50.24	11.55	8.50	126	30.3	31.0	4H 10M	DISCHARGE STOPPED EARLY ON WRONG CUT OFF VOLTAGE
Cycle 191	05/19/88	21W/KG	57.71	10.28	151.0	27.6	28.5	46M	05/19/88	75.68	16.69	8.69	131	33.2	33.9	6H 10M	
Cycle 192	05/20/88	42W/KG	42.95	7.14	138.0	32.0	33.3	16M	05/20/88	65.69	14.77	7.96	152	27.8	29.5	6H 10M	
Cycle 193	05/23/88	42W/KG	39.02	6.46	138.0	31.2	32.4	14.5M	05/23/88	66.30	14.95	8.01	169	31.1	32.4	6M 25M	
Cycle 194																	

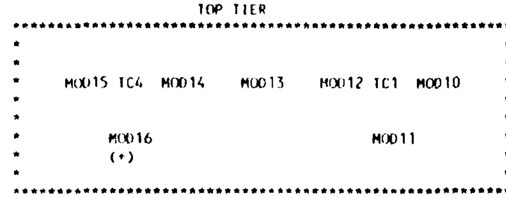
Acronyms:

- ABOD Amps Battery Out Discharge
- EBOD Energy Battery Out Discharge
- EDT Avg. Ending Discharge Temperature
- DR Discharge (A-Amps, P-Power Kw, F-FUDS Cycle)
- DCV Discharge Cutoff Voltage (* varies due to time interval spacing)
- TTD Total Time of Discharge
- ABIR Amps Battery In Recharge
- EBIR Energy Battery In Recharge
- CC End of Charge Current
- ECT Avg. Ending Charge Temperature
- TTOC Total Time of Charge

BOTTOM TIER



TOP TIER



NOTES.
1. 48 CYCLES WERE ON PACK WHEN RECIEVED FROM FORD.
2. TOTAL BATTERY PACK INCLUDING CASE, WATERING SYSTEM, & INSTRUMENTATION, WEIGHS 634 KG (1395 lbs.)
3. ESTIMATED RANGE OF DSEP I VEHICLE ON S FUDS79 IS 41.2 KM (25.75 MILES)
4. ALL CHARGES DONE IN THE BATTERY LAB.,EXCEPT EQUALIZATION CHARGES, WERE DONE WITH SPEGEL CHARGER, CYCLES DONE IN DYNO LAB. UP TO CYCLE 131 ON 1/12/88 WERE DONE WITH B.M.S., AFTER THAT SPEGEL CHARGER WAS USED

APPENDIX D

DYNAMOMETER TEST SUMMARY TABLES

TEST DATA--ETX-1

Test	XIDAC1	XIDA02	XIDEE1	XIDEE2	
Test Type	Acceleration	Acceleration	Energy Consumption	Energy Consumption	
Test Date	8/24/87	10/28/87	8/26/87	10/29/87	
Range (km)	94.53	110.28	120.33	126.74	
No. of Cycles	--	--	--	--	
Test Time (min)	133.8	137.8	147.4	156.6	
Term Voltage	160	160	160	160	
Battery Cycle No.	82	101	83	102	
AC Energy Consumption Wh/km	--[a]	295[b]	229	223	
System dc Energy Consumption (Wh/km)	219	263	204	199	
Vehicle dc Energy Consumption Gross (Wh/km)	145[c]	136	131	133	
Vehicle dc Energy Consumption Net Wh/km	143	133	130	132	
Battery Discharge Energy (kWh)	13.747	14.963	15.747	16.819	
Battery Regeneration Energy (kWh)	0.243	0.274	0.052	0.098	
Battery Discharge (Ah)	77.69	83.91	87.42	93.91	
Battery Regeneration (Ah)	1.13	1.28	0.25	0.47	
Average Battery Temperature Test Start #C	22.3	28.0	23.5	27.8	
Average Battery Temperature Test End #C	28.9	33.9	28.9	31.8	
Recharge Energy dc (kWh)	20.721	28.995[b]	24.551	25.237	
Recharge Energy ac (kWh)	--[a]	32.560[b]	27.560	28.267	
Recharge Amperage (Ah)	94.59	128.47[b]	109.59	113.55	
Battery Energy Recharge Efficiency (%)	65.2	50.7[b]	63.9	66.3	
Battery Coulombic Recharge Efficiency (%)	80.9	64.3[b]	79.5	82.3	
Recharge Time (min)	470[a]	576[b]	380	395	
Average Battery Temperature Recharge Start #C	29.5	31.0	28.1	30.6	
Average Battery Temperature Recharge End #C	38.9	41.6	39.3	40.1	
Wall-ac-Efficiency %	--[a]	45.1[b]	56.9	59.2	
Auxiliary Battery Energy Discharge (kW/h)	0.333	0.488	0.500	0.432	
Auxiliary Battery Energy Charge (kW/h)	--	--	--	--	

a. Used Spegel charger--ac energy was not measured.

b. Equilization charge.

c. Vehicle had some dropout problems during 40% SOC accelerations.

TEST DATA--ETX-1

Test	XIDF01	XIDF02[b]	XIDF03[c]	XDF03A	XDF04A[d]
Test Type	Par Regen FUDS	Par Regen FUDS	Par Regen FUDS	Par Regen FUDS	Split Region FUDS
Test Date	9/1/87	12/7/87	12/10/87	12/22/87	1/19/88
Range (km)	64.88	55.51	61.33	61.16	59.04[d]
No. of Cycles	5 stop at 380 sec CY-6	4 stop ~800 sec CY-5	5	5 stopped ~200 sec	4 + 1160 sec
Test Time (min)	170.9	145.3	168.1	168.0	151.1
Term Voltage	133	133	133	133	133
Battery Cycle No.	86	113	116	121	135
AC Energy Consumption Wh/km	394	529[a]	388	380	337[d]
System dc Energy Consumption (Wh/km)	351	471	346	339	306
Vehicle dc Energy Consumption Gross (Wh/km)	214	226[b]	228[c]	223	221
Vehicle dc Energy Consumption Net Wh/km	203	206	208	202	199
Battery Discharge Energy (kWh)	13.855	12.546	13.980	13.617	13.021
Battery Regeneration Energy (kWh)	0.696	1.098	1.231	1.282	1.274
Battery Discharge (Ah)	80.78	74.42	82.16	78.35	76.44
Battery Regeneration (Ah)	3.26	5.26	5.99	6.23	5.91
Average Battery Temperature Test Start #C	25.2	21.1	24.5	25.3	24.3
Average Battery Temperature Test End #C	33.3	29.2	31.9	33.3	32.8
Recharge Energy dc (kWh)	22.801	26.156[a]	21.220	20.738	18.094
Recharge Energy ac (kWh)	25.572	29.350[a]	23.774	23.262	19.887
Recharge Amperage (Ah)	101.34	115.18[a]	94.48	92.76	82.37
Battery Energy Recharge Efficiency (%)	57.7	43.8	60.1	59.5	64.9[d]
Battery Coulombic Recharge Efficiency (%)	76.5	60.0	80.6	77.7	85.6
Recharge Time (min)	360	545[a]	345	340	405
Average Battery Temperature Recharge Start #C	32.1	26.9	26.5	29.9	29.9
Average Battery Temperature Recharge End #C	36.2	41.0	37.2	38.9	36.5
Wall-ac-Efficiency %	51.5	39.0[a]	53.6	53.0	59.1
Auxiliary Battery Energy Discharge (kW/h)	0.444	0.374	0.433	0.503	0.437
Auxiliary Battery Energy Charge (kW/h)	--	--	--	--	--

a. Equilization charge.

b. Dyno cooled 45 min before start of test - Invalid test.
c. Void Test - TB current measurement noisy.

d. Used Spegel charger.

TEST DATA ETX-1

Test	XIDSF1	XDSF2A			
Test Type	S-FUDS	S-FUDS			
Test Date	9/2/87	12/18/87			
Range (km)	63.80	60.11			
No. of Cycles	20 stop on 21	19 stop on 20			
Test Time (min)	175.0	158.9			
Term Voltage	133	133			
Battery Cycle No.	87	119			
AC Energy Consumption Wh/km	374	484[a]			
System dc Energy Consumption (Wh/km)	334	430			
Vehicle dc Energy Consumption Gross (Wh/km)	207	213			
Vehicle dc Energy Consumption Net Wh/km	196	196[b]			
Battery Discharge Energy (kWh)	13.217	12.790			
Battery Regeneration Energy (kWh)	0.690	1.035			
Battery Discharge (Ah)	76.81	75.14			
Battery Regeneration (Ah)	3.16	4.58			
Average Battery Temperature Test Start #C	23.1	26.6			
Average Battery Temperature Test End #C	32.2	33.2			
Recharge Energy dc (kWh)	21.304	25.849[a]			
Recharge Energy ac (kWh)	23.853	29.069[a]			
Recharge Amperage (Ah)	94.38	113.65			
Battery Energy Recharge Efficiency (%)	58.8	45.5[a]			
Battery Coulombic Recharge Efficiency (%)	73.7	62.1			
Recharge Time (min)	345	515[a]			
Average Battery Temperature Recharge Start #C	31.2	26.8			
Average Battery Temperature Recharge End #C	36.5	42.8			
Wall-ac-Efficiency %	52.5	40.4[a]			
Auxiliary Battery Energy Discharge (kW/h)	0.455	0.516			
Auxiliary Battery Energy Charge (kW/h)	--	--			

a. Equilization charge.

b. Regeneration circuit repaired and setup prior to test run on 11/24/87.

TEST DATA ETX-1

Test	XIDDIB	XIDND1	XIDD02	XIDD03	XIDND2
Test Type	Par Regen D-Cycle	Noncont Par Regen D-Cycle	Split Regen D-Cycle	Par Regen D-Cycle	Par Regen Noncont D-Cycle
Test Date	8/31/87	9/3/87	9/9/87	11/2/87	11/24/87
Range (km)	60.87	64.68	58.21	59.28	54.05
No. of Cycles	38	40	36	37	35
Test Time (min)	78.7	143.0	74.5	76.2	133.3
Term Voltage	133	133	133	133	133
Battery Cycle No.	85	98	99	104	107
AC Energy Consumption Wh/km	346	446[a]	366	362	498[a]
System dc Energy Consumption (Wh/km)	309	397[a]	327	324	444
Vehicle dc Energy Consumption Gross (Wh/km)	199	197	195	197	210[c]
Vehicle dc Energy Consumption Net Wh/km	186	180	174	174	188[c]
Battery Discharge Energy (kWh)	12.120	12.729	11.363[b]	11.681	11.363
Battery Regeneration Energy (kWh)	0.809	1.082	1.240	0.660[d]	1.194
Battery Discharge (Ah)	70.87	73.31	65.62	68.27	65.79
Battery Regeneration (Ah)	3.87	4.47	5.82	3.16	5.074
Average Battery Temperature Test Start #C	23.3	25.3	22.3	22.7	25.7
Average Battery Temperature Test End #C	33.5	34.1	32.6	31.7	33.1
Recharge Energy dc (kWh)	18.792	25.683[a]	19.040	19.216	23.978[a]
Recharge Energy ac (kWh)	21.034	28.859[a]	21.278	21.471	26.914[a]
Recharge Amperage (Ah)	83.94	112.959	83.03	85.46	104.61
Battery Energy Recharge Efficiency (%)	60.2	45.3[a]	53.2	57.4	42.4[a]
Battery Coulombic Recharge Efficiency (%)	79.8	60,9[a]	72.0	76.2	58.1
Recharge Time (min)	280	505[a]	325	315	500
Average Battery Temperature Recharge Start #C	31.8	33.2	29.7	29.9	28.9
Average Battery Temperature Recharge End #C	43.0	46.6	35.1	38.2	40.5
Wall-ac-Efficiency %	53.8	40.3[a]	47.6	51.3	37.8[a]
Auxiliary Battery Energy Discharge (kW/h)	0.190	0.223	0.210	0.186	0.230
Auxiliary Battery Energy Charge (kW/h)	--	--	--	--	--

a. Equilization charge.

b. Battery charger remained on-line from 9/3/87 to start of test--appears BMS doesn't keep TB fully charged.

c. Regen circuit repaired and set-up before test. Gross energy consumption high--repeated the test--XDND2A.

d. Low regen test invalid.

TEST DATA ETX-1

Test	XDD03A	XDD05	XDND2A	XIDD04	XDND2B
Test Type	Par Regen D-Cycle	No Regen D-Cycle	Par Regen Non Cont D-Cycle	Split Regen D-Cycle	Par Regen Non Cont D-Cycle
Test Date	12/2/87	12/8/87	12/9/87	12/23/87	1/6/88
Range (km)	53.03	52.84	59.56	57.87	57.58
No. of Cycles	33	33	37	37[b]	37[b]
Test Time (min)	68.0	68.1	137.4	76.4	138.3
Term Voltage	133	133	133	133	133
Battery Cycle No.	110	114	115	122	127
AC Energy Consumption Wh/km	350	379	349	350	472[a]
System dc Energy Consumption (Wh/km)	314	339	312	312	419[a]
Vehicle dc Energy Consumption Gross (Wh/km)	201	202	204	200	202
Vehicle dc Energy Consumption Net Wh/km	182	202	182	179	183
Battery Discharge Energy (kWh)	10.658	10.653	12.126	11.580	11.631
Battery Regeneration Energy (kWh)	1.023	0	1.277	1.229	1.088
Battery Discharge (Ah)	60.78	62.25	71.10	66.91	67.34
Battery Regeneration (Ah)	4.90	0	5.35	5.80	5.12
Average Battery Temperature Test Start #C	26.2	24.6	24.2	25.4	23.4
Average Battery Temperature Test End #C	33.9	31.6	31.7	33.9	31.6
Recharge Energy dc (kWh)	16.650	17.901	18.575	18.055	24.113[a]
Recharge Energy ac (kWh)	18.564	20.008	20.816	20.246	27.171[a]
Recharge Amperage (Ah)	73.39	79.72	82.59	80.272	105.63
Battery Energy Recharge Efficiency (%)	57.9	59.5	58.4	57.3	43.7[a]
Battery Coulombic Recharge Efficiency (%)	76.1	78.1	79.6	76.1	58.9
Recharge Time (min)	270	285	310	290	495[a]
Average Battery Temperature Recharge Start #C	27.2	29.1	26.3	28.3	29.2
Average Battery Temperature Recharge End #C	37.0	37.0	35.2	38.4	42.3
Wall-ac-Efficiency %	51.9	53.2	52.1	51.1	38.8[a]
Auxiliary Battery Energy Discharge (kW/h)	0.179	0.188	0.233	0.261	0.214
Auxiliary Battery Energy Charge (kW/h)	--	--	--	--	--

a. Equilization charge.

b. Vehicle problems--late acceleration on 2 cycles--test valid.

TEST DATA ETX-1

Test	XIDD06	XIDD07[a]	XIDD08		
Test Type	No Regen D-Cycle	Par Regen D-Cycle	Par Regen D-Cycle		
Test Date	1/8/88	1/12/88	3/22/88		
Range (km)	52.68	64.61	59.37		
No. of Cycles	33	40	37		
Test Time (min)	66.97	82.73	76.22		
Term Voltage	133	133	133		
Battery Cycle No.	129	131	154		
AC Energy Consumption Wh/km	383	305	334		
System dc Energy Consumption (Wh/km)	339	278	305		
Vehicle dc Energy Consumption Gross (Wh/km)	199	199	201		
Vehicle dc Energy Consumption Net Wh/km	199	179	181		
Battery Discharge Energy (kWh)	10.504	12.850	11.955		
Battery Regeneration Energy (kWh)	0	1.280	1.181		
Battery Discharge (Ah)	60.84	75.22	68.89		
Battery Regeneration (Ah)	0	5.98	5.58		
Average Battery Temperature Test Start #C	25.3	28.0	22.5		
Average Battery Temperature Test End #C	33.6	36.6	31.9		
Recharge Energy dc (kWh)	17.878	17.979	18.095		
Recharge Energy ac (kWh)	20.181	19.730	19.831		
Recharge Amperage (Ah)	79.48	81.88	80.87		
Battery Energy Recharge Efficiency (%)	58.8	64.3	59.5		
Battery Coulombic Recharge Efficiency (%)	76.5	84.6	78.3		
Recharge Time (min)	275	400[a]	435		
Average Battery Temperature Recharge Start #C	31.0	30.7	22.2		
Average Battery Temperature Recharge End #C	41.9	35.6	25.8		
Wall-ac-Efficiency %	52.0	58.6	54.3		
Auxiliary Battery Energy Discharge (kW/h)	0.182	0.243	0.196		
Auxiliary Battery Energy Charge (kW/h)	--	0	0		

a. Start of testing using Spegel charger.

TEST DATA ETX-1

Test	XDF05A	XIDF06	XIDF07	XDF05B	
Test Type	FUDS Split[a]	FUDS Par. Regen.	FUDS Par. Regen.	FUDS Split Regen.	
Test Date	2/19/88	3/23/88	3/28/88	3/29/88	
Range (km)	61.72	61.81	59.66[b]	60.21	
No. of Cycles	5 stop ~ 230 s in Cycle 6	5 stop ~ 230 in Cycle 6	5 stop at end of 5	5 stop at end of 5	
Test Time (min)	168.7	168.20	154.6	154.6	
Term Voltage	133	133	133	133	
Battery Cycle No.	148	155	158	159	
AC Energy Consumption Wh/km	353	371	378	370	
System dc Energy Consumption (Wh/km)	320	339	345[c]	338[c]	
Vehicle dc Energy Consumption Gross (Wh/km)	232[a]	227	223[c]	223[c]	
Vehicle dc Energy Consumption Net Wh/km	211	206	203[c]	202[c]	
Battery Discharge Energy (kWh)	14.317	14.033	13.331	13.447	
Battery Regeneration Energy (kWh)	1.315	1.283	1.211	1.301	
Battery Discharge (Ah)	82.19	80.10	77.27	77.04	
Battery Regeneration (Ah)	5.80	6.00	5.74	6.19	
Average Battery Temperature Test Start #C	22.6	22.6	21.5	22.4	
Average Battery Temperature Test End #C	30.5	31.0	32.0	32.3	
Recharge Energy dc (kWh)	19.770	20.925	20.571	20.341	
Recharge Energy ac (kWh)	21.789	22.934	22.547	22.306	
Recharge Amperage (Ah)	90.51	93.64	92.13	90.96	
Battery Energy Recharge Efficiency (%)	65.8	60.9	58.9	59.7	
Battery Coulombic Recharge Efficiency (%)	84.4	79.1	77.6	77.9	
Recharge Time (min)	420	510	495	490	
Average Battery Temperature Recharge Start #C	29.9	24.9	28.5	29.6	
Average Battery Temperature Recharge End #C	38.1	26.6	28.9	26.8	
Wall-ac-Efficiency %	59.7	55.6	53.8	54.5	
Auxiliary Battery Energy Discharge (kW/h)	0.442	0.389	0.421	0.426	
Auxiliary Battery Energy Charge (kW/h)	0.0	0.0	0.0	0.0	

a. Shift problem Cycle 1 - missed part of 163 s excursion - Invalid Test. All tests this page used Spegel charger.

b. Missed gear shift at start of 91 kW/h segment of Cycle 4.

c. Cycle 5 was run on a best effort basis (10 min rest adds 0.127 kWh to battery energy).

TEST DATA ETX-1

Test	XIDC01	XIDNC1	XIDC02	XIDC03[b]	XDC03B
Test Type	Par. Regen C-Cycle	Non Cont Par. Reg C-Cycle	Split Regen C-Cycle	Par. Regen C-Cycle	Par. Regen C-Cycle
Test Date	08/18/87	09/11/87	10/27/87	11/03/87	12/01/87
Range (km)	62.85	71.19	66.70	67.56	56.19
No. of Cycles	110	125	117	118	99
Test Time (min)	146.0	289.3	155.2	156.2	131.3
Term Voltage	133	133	133	133	133
Battery Cycle No.	79	91	100	105	109
AC Energy Consumption (Wh/km)	374	466[a]	358	374	373
System dc Energy Consumption (Wh/km)	333	358	319	335	333
Vehicle dc Energy Consumption Gross (Wh/km)	210	207	209	211	214
Vehicle dc Energy Consumption Net Wh/km	202	196	202	209	198
Battery Discharge Energy (kWh)	13.186	14.710	13.937	14.258	12.010
Battery Regeneration Energy (kWh)	0.493	0.759	0.467	0.170	0.883
Battery Discharge (Ah)	75.19	83.90	78.60	81.60	68.20
Battery Regeneration (Ah)	2.31	2.03	2.09	0.71	4.21
Average Battery Temperature Test Start #C	22.9	23.0	25.8	26.1	21.3
Average Battery Temperature Test End #C	31.6	30.0	32.6	32.3	28.7
Recharge Energy dc (kWh)	20.947	25.509	21.265	22.607	18.703
Recharge Energy ac (kWh)	23.511	33.140[a]	23.861	25.288	20.947
Recharge Amperage (Ah)	93.73	129.30	95.28	101.06	82.63
Battery Energy Recharge Efficiency (%)	60.6	54.7	63.3	62.3	59.5
Battery Coulombic Recharge Efficiency (%)	77.7	63.3	80.3	80.0	77.4
Recharge Time (min)	345	575	345	365	310
Average Battery Temperature Recharge Start #C	30.8	28.4	28.3	29.4	25.4
Average Battery Temperature Recharge End #C	34.1	35.9	38.5	38.5	37.4
Wall-ac-Efficiency %	54.0	42.1[a]	56.4	55.7	53.1
Auxiliary Battery Energy Discharge (kW/h)	0.327	0.332	0.540	0.441	0.417
Auxiliary Battery Energy Charge (kW/h)	--	--	--	--	--

a. Equilization charge.

b. Regeneration diminished.

TEST DATA ETX-1

Test	XIDC04	XIDC05	XIDNC2	XIDC06	XIDC07[c]
Test Type	Split Regen C-Cycle	No Regen C-Cycle	Non Cont Par. Regen C-Cycle	No Regen C-Cycle	Par Regen C-Cycle
Test Date	12/03/87	12/04/87	12/21/87	01/07/88	01/14/88
Range (km)	65.06	63.26[a]	59.09	62.92[b]	70.57
No. of Cycles	114	110[a]	104	110[b]	123
Test Time (min)	151.1	146.0	225.9	145.0	163.5
Term Voltage	133	133	133	133	133
Battery Cycle No.	111	112	120	128	133
AC Energy Consumption (Wh/km)	346	--	362	399	331[c]
System dc Energy Consumption (Wh/km)	309	346	324	356	301
Vehicle dc Energy Consumption Gross (Wh/km)	211	219	211	213	208
Vehicle dc Energy Consumption Net Wh/km	193	219	191	213	191
Battery Discharge Energy (kWh)	13.704	13.834	12.483	13.400	14.664[c]
Battery Regeneration Energy (kWh)	1.161	0.0	1.198	0.0	1.212
Battery Discharge (Ah)	76.98	78.94	73.88	76.17	84.63
Battery Regeneration (Ah)	5.66	0.0	4.33	0.0	5.56
Average Battery Temperature Test Start #C	25.7	26.1	20.5	26.9	26.5
Average Battery Temperature Test End #C	31.9	31.3	27.3	31.3	33.3
Recharge Energy dc (kWh)	20.119	21.873	19.127	22.382	21.256
Recharge Energy ac (kWh)	22.525	--	21.405	25.105	23.355
Recharge Amperage (Ah)	90.24	97.91	84.84	99.61	96.66
Battery Energy Recharge Efficiency (%)	62.3	63.2	59.0	59.9	63.3
Battery Coulombic Recharge Efficiency (%)	79.0	80.6	82.0	76.5	81.8
Recharge Time (min)	330	350	310	365	475
Average Battery Temperature Recharge Start #C	30.9	26.9	24.9	30.3	29.8
Average Battery Temperature Recharge End #C	39.4	37.5	36.9	40.4	38.3
Wall-ac-Efficiency %	55.7	--	52.7	53.4	57.6
Auxiliary Battery Energy Discharge (kW/h)	0.509	0.384	0.343	0.431	0.451
Auxiliary Battery Energy Charge (kW/h)	--	--	--	--	--

a. Stopped during Cycle III.

b. Stopped at end of Cycle 110

c. Using Spegel charger.

TEST DATA ETX-1

Test	XIDC08				
Test Type	Split Regen C-Cycle				
Test Date	01/20/88				
Range (km)	64.69				
No. of Cycles	114[a]				
Test Time (min)	150.3[a]				
Term Voltage	133				
Battery Cycle No.	136				
AC Energy Consumption (Wh/km)	319[b]				
System dc Energy Consumption (Wh/km)	290				
Vehicle dc Energy Consumption Gross (Wh/km)	212				
Vehicle dc Energy Consumption Net Wh/km	193				
Battery Discharge Energy (kWh)	13.723[b]				
Battery Regeneration Energy (kWh)	1.221				
Battery Discharge (Ah)	78.71				
Battery Regeneration (Ah)	5.50				
Average Battery Temperature Test Start #C	24.2				
Average Battery Temperature Test End #C	30.8				
Recharge Energy dc (kWh)	18.764				
Recharge Energy ac (kWh)	20.617				
Recharge Amperage (Ah)	85.23				
Battery Energy Recharge Efficiency (%)	66.6[b]				
Battery Coulombic Recharge Efficiency (%)	85.9[b]				
Recharge Time (min)	425				
Average Battery Temperature Recharge Start #C	27.3				
Average Battery Temperature Recharge End #C	34.9				
Wall-ac-Efficiency %	60.6				
Auxiliary Battery Energy Discharge (kW/h)	0.465				
Auxiliary Battery Energy Charge (kW/h)	--				

a. Missed 8 full cycles because of dropouts - only one was partially run cycle.

b. Spegel charger.

TEST DATA ETX-1

Test	XID481	XD482B	XID483	XID484	XID485
Test Type	48 km/h	48 km/h	Access on 48 km/h	Access on 48 km/h	48 km/h
Test Date	08/06/87	10/26/87	09/10/87	01/11/88	01/13/88
Range (km)	133.01	126.46	131.89	109.90	115.75
No. of Cycles	--	--	--	--	--
Test Time (min)	167.0	159.2	167.3	137.7	145.1
Term Voltage	160	160	160	160	160
Battery Cycle No.	77	99	90	130	132
AC Energy Consumption (Wh/km)	214	207	208	223	198[a]
System dc Energy Consumption (Wh/km)	190	185	186	198	180
Vehicle dc Energy Consumption Gross (Wh/km)	125	124	120	127	129
Vehicle dc Energy Consumption Net Wh/km	125	124	120	126	129
Battery Discharge Energy (kWh)	16.627	15.659	15.784	13.908	14.913
Battery Regeneration Energy (kWh)	0.003	0.008	0.002	0.009	0.02
Battery Discharge (Ah)	90.58	85.63	86.60	76.53	82.95
Battery Regeneration (Ah)	0.02	0.04	0.003	0.05	0.08
Average Battery Temperature Test Start #C	25.1	24.9	22.5	23.4	24.9
Average Battery Temperature Test End #C	29.3	30.2	27.9	27.9	28.9
Recharge Energy dc (kWh)	25.335	23.397	24.510	21.785	20.843
Recharge Energy ac (kWh)	28.469	26.221	27.421	24.533	22.903
Recharge Amperage (Ah)	111.86	104.68	108.57	97.68	95.31
Battery Energy Recharge Efficiency (%)	65.6	66.9	64.4	63.8	71.5[a]
Battery Coulombic Recharge Efficiency (%)	81.0	81.8	79.8	78.3	86.9[a]
Recharge Time (min)	395	370	385	360	460[a]
Average Battery Temperature Recharge Start #C	25.9	28.4	25.8	26.3	27.8
Average Battery Temperature Recharge End #C	--	38.7	34.9	38.1	36.2
Wall-ac-Efficiency %	58.4	59.7	57.6	56.7	65.1
Auxiliary Battery Energy Discharge (kW/h)	0.543	0.442	1.214	1.031	0.368
Auxiliary Battery Energy Charge (kW/h)	--	--	--	--	--

a. Used Spegel charger before and after this test.

TEST DATA ETX-1

Test	XID486[a]	XD486A[a]			
Test Type	48 km/h	48 km/h			
Test Date	02/22/88	03/24/88			
Range (km)	120.14	127.46			
No. of Cycles	--	--			
Test Time (min)	150.6	160.4			
Term Voltage	160	160			
Battery Cycle No.	149	156			
AC Energy Consumption (Wh/km)	203	195			
System dc Energy Consumption (Wh/km)	184	177			
Vehicle dc Energy Consumption Gross (Wh/km)	132[b]	126			
Vehicle dc Energy Consumption Net Wh/km	132	126			
Battery Discharge Energy (kWh)	15.833	16.011			
Battery Regeneration Energy (kWh)	0.016	0.0009			
Battery Discharge (Ah)	85.57	87.08			
Battery Regeneration (Ah)	0.08	0.004			
Average Battery Temperature Test Start #C	22.4	22.0			
Average Battery Temperature Test End #C	27.0	26.4			
Recharge Energy dc (kWh)	22.143	22.583			
Recharge Energy ac (kWh)	24.389	24.807			
Recharge Amperage (Ah)	101.45	101.94			
Battery Energy Recharge Efficiency (%)	71.4	70.9			
Battery Coulombic Recharge Efficiency (%)	84.3	85.4			
Recharge Time (min)	485	525			
Average Battery Temperature Recharge Start #C	25.9	21.6			
Average Battery Temperature Recharge End #C	35.9	27.2			
Wall-ac-Efficiency %	64.9	64.5			
Auxiliary Battery Energy Discharge (kW/h)	0.286	0.356			
Auxiliary Battery Energy Charge (kW/h)	0	0			

a. Spegel charger.

b. Excessive Energy consumption-invalid test.

TEST DATA ETX-1

Test	XID641	XID642	XID643[b]	XID644[b]	XID644A[c]
Test Type	64 km/h	64 km/h	64 km/h	64 km/h	64 km/h
Test Date	08/20/87	10/30/87	01/15/88	02/23/88	02/25/88
Range (km)	101.22	111.27	103.36	104.46	105.80
No. of Cycles	--	--	--	--	--
Test Time (min)	95.2	106.7	98.5	99.0	99.5
Term Voltage	160	160	160	160	160
Battery Cycle No.	80	103	134	150	151
AC Energy Consumption (Wh/km)	307	235	207	214	222
System dc Energy Consumption (Wh/km)	273	210	189	194	203
Vehile dc Energy Consumption Gross (Wh/km)	132	133	133	137[d]	136[d]
Vehile dc Energy Consumption Net Wh/km	131	133	133	137	135
Battery Discharge Energy (kWh)	13.329	14.828	13.758	14.327	14.352
Battery Regeneration Energy (kWh)	0.029	0.015	0.03	0.03	0.03
Battery Discharge (Ah)	73.12	82.36	76.67	79.14	78.40
Battery Regeneration (Ah)	0.13	0.07	0.15	0.13	0.16
Average Battery Temperature Test Start #C	23.2	27.0	26.9	25.9	25.4
Average Battery Temperature Test End #C	30.1	31.7	31.7	30.5	29.6
Recharge Energy dc (kWh)	27.610	23.327	19.484	20.314	21.452
Recharge Energy ac (kWh)	31.045[a]	26.125	21.428	22.364	23.528
Recharge Amperage (Ah)	120.83	104.42	89.18	92.89	96.27
Battery Energy Recharge Efficiency (%)	48.2[a]	63.5	70.4	70.5	66.8
Battery Coulombic Recharge Efficiency (%)	60.4[a]	78.8	85.8	85.1	81.3
Recharge Time (min)	555[a]	375	430	450	525
Average Battery Temperature Recharge Start #C	29.3	29.4	30.4	28.6	--
Average Battery Temperature Recharge End #C	40.1	39.7	37.5	37.0	--
Wall-ac-Efficiency %	42.8[a]	56.7	64.1[b]	64.0[b]	--
Auxiliary Battery Energy Discharge (kW/h)	0.113	0.249	0.195	0.202	0.155
Auxiliary Battery Energy Charge (kW/h)	--	--	0	0	0

a. Equilization charge.

b. Spegel charger.

c. Recalibrated battery measurements & Dyno before to test - still excess energy consumption.

d. Excessive energy consumption.

TEST DATA ETX-1

Test	XID644C				
Test Type	64 km/h				
Test Date	03/21/88				
Range (km)	90.21				
No. of Cycles	--				
Test Time (min)	85.1				
Term Voltage	160				
Battery Cycle No.	153				
AC Energy Consumption (Wh/km)	277				
System dc Energy Consumption (Wh/km)	253				
Vehicle dc Energy Consumption Gross (Wh/km)	132				
Vehicle dc Energy Consumption Net Wh/km	132				
Battery Discharge Energy (kWh)	11.940				
Battery Regeneration Energy (kWh)	0.064				
Battery Discharge (Ah)	65.81				
Battery Regeneration (Ah)	0.31				
Average Battery Temperature Test Start #C	22.2				
Average Battery Temperature Test End #C	27.1				
Recharge Energy dc (kWh)	22.789				
Recharge Energy ac (kWh)	24.971				
Recharge Amperage (Ah)	100.72				
Battery Energy Recharge Efficiency (%)	52.1[a]				
Battery Coulombic Recharge Efficiency (%)	65.0[a]				
Recharge Time (min)	577				
Average Battery Temperature Recharge Start #C	25.5				
Average Battery Temperature Recharge End #C	26.7				
Wall-ac-Efficiency %	47.6[a]				
Auxiliary Battery Energy Discharge (kW/h)	0.145				
Auxiliary Battery Energy Charge (kw/h)	0				

Test XD664B was invalid-two operations personnel related dropouts.

a. Traction battery has been inactive for 23 days.

TEST DATA ETX-1

Test	XID881	XD882B	XID883	XID884[b]	XID885[b]
Test Type	88 km/hr	88 km/hr	88 km/hr	88 km/hr	88 km/hr
Test Date	08/21/87	10/23/87	11/25/87	11/22/88	03/25/88
Range (km)	69.83	61.14	65.00	61.12	70.57
No. of Cycles	--	--	--	--	--
Test Time (min)	48.5	42.3	45.3	42.3	49.6
Term Voltage	160	160	160	160	160
Battery Cycle No.	81	98	108	138	157
AC Energy Consumption (Wh/km)	380[a]	388[a]	291	275[b]	263
System dc Energy Consumption (Wh/km)	338	343	260	251	240
Vehicle dc Energy Consumption Gross (Wh/km)	159	158	164	166	159
Vehicle dc Energy Consumption Net Wh/km	159	157	163	165	159
Battery Discharge Energy (kWh)	11.106	9.664	10.662	10.154	11.215
Battery Regeneration Energy (kWh)	0.029	0.046	0.065	0.06	0.024
Battery Discharge (Ah)	61.98	54.16	59.93	57.23	62.68
Battery Regeneration (Ah)	0.14	0.23	0.32	0.28	0.12
Average Battery Temperature Test Start #C	25.7	23.5	26.8	25.9	23.7
Average Battery Temperature Test End #C	31.0	31.2	33.7	32.3	31.0
Recharge Energy dc (kWh)	23.575	21.076[a]	16.925	15.346[b]	16.933
Recharge Energy ac (kWh)	26.531	23.700[a]	18.886	16.816	18.589
Recharge Amperage (Ah)	103.66	92.47[a]	75.14	69.05	77.06
Battery Energy Recharge Efficiency (%)	47.0[a]	45.6[a]	56.1	65.8[b]	66.1[b]
Battery Coulombic Recharge Efficiency (%)	59.7	58.3	79.3	82.5[b]	81.2[b]
Recharge Time (min)	475[a]	430	260	360	380
Average Battery Temperature Recharge Start #C	31.3	28.5	29.7	25.2	30.5
Average Battery Temperature Recharge End #C	43.2	48.5	39.0	31.3	37.3
Wall-ac-Efficiency %	41.8[a]	40.6[a]	56.1	60.0[b]	60.2[b]
Auxiliary Battery Energy Discharge (kW/h)	0.070	0.074	0.081	0.085	0.061
Auxiliary Battery Energy Charge (kW/h)	--	--	--	0	0

a. Equilization charge.

b. Spegel charger.