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RESULTS OF BASELINE TESTS OF THE EVA METRO SEDAN, CITI-CAR, JET INDUSTRIES ELECTRA-VAN, CDA TOWN CAR, AND OTIS P-500 VAN

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16. Abstract

Five electric vehicles were tested at vehicle test tracks using the SAE Vehicle Test Procedure - SAE 227a. The tests provide range data at steady speeds and for several driving cycles. Most tests were conducted with lead-acid traction batteries. The Otis Van and the Copper Electric Town Car were also tested with lead-acid and NASA nickel-zinc batteries. The tests showed a range increase of from 82 to 101 percent depending on vehicle, speed, and test cycle.

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SUMMARY

This report covers the initiation of a task to develop baseline test data which will allow ERDA to assess the state-of-the-art for electric vehicles. Such an assessment can be used (1) as a benchmark for measuring progress, (2) to help formulate standards and specifications for government purchase of electric vehicles, and (3) to determine areas where technology improvements are needed. Presented herein are the preliminary results of tests of five electric vehicles conducted according to selected procedures recommended in Electric Vehicle Test Procedure - SAE J227a. The SAE recommended practice was selected by mutual agreement with the ERDA Program Manager.

The tests reported herein were undertaken for several reasons with differing objectives. Tests on the EVA Metro sedan, Citi-car, and Jet Industries Electra-van were conducted to establish baseline data. However, the EVA tests conducted in 1976 were also intended to repeat tests first performed on these vehicles for ERDA in 1975. Special tests were also conducted on an Otis P-500 van to obtain comparative range data available from an experimental nickel-zinc battery compared to a conventional lead-acid traction battery. A high-performance experimental electric sedan, the Copper Development Association Copper Electric Town Car was also tested with standard and experimental lead-acid batteries and the NASA nickel-zinc battery.

The results are presented in two parts. The first entitled "Baseline Tests" reports the results of the EVA, Citi-car and Electra-van tests. The second part, "Special Tests" details the Otis P-500 and CDA results.

Table 1 presents a summary of the results obtained through August 1976. The EVA sedan provided ranges at constant speed of 43 miles at 25 mph to 22 miles at 53 mph. It also traveled 20 miles on the SAE Schedule C driving cycle. The Citi-car had a top speed of 32 mph and was able to travel from 53 miles at 18 mph to 36 miles at 25 mph and 25 miles at top speed. It ran approximately 20 miles on both the Schedule B and Schedule C cycles. The Electra-van traveled 70 miles at 20 mph, 46 miles at 30 mph, and 40 miles at 40 mph. Ranges over the driving Schedules B and C were 45 and 23 miles, respectively.

The comparative battery performance tests using the Otis P-500 Utility Van and the CDA Town Car showed an 82 to 101 percent range increase (depending on vehicle, speed, and cycle) for the LeRC nickel-zinc battery over the standard EV-106 lead-acid battery. Of special significance was the 146.3 mile range (at 40 mph obtained with the CDA vehicle powered with the nickel-zinc battery.

TABLE 1. - SUMMARY OF PRELIMINARY RESULTS OF BASELINE TESTS THROUGH AUGUST 1976

	Range at steady speed, mph							Top speed	SAE J227a Driving Cycle Sch. Range, miles				Road energy consumption, KWH/mi.	
		20	25	30	35	40	45		Sch. A 10 mph	Sch. B 20 mph	Sch. C 30 mph	Sch. D 45 mph	at 25 mph	at 40 mph
Baseline Test Vehicles														
EVA Metro Sedan EV-106 Lead-acid batteries								(53 mph)						
1975 Test			56.4		34		27.7	20.3			21.6		0.12	0.19
1976 Test, after 947 miles			42.7		35.3		28.5	22.2			19.6			
Sebring-Vanguard Citi-car EV-106 Lead-acid batteries	42.6 at 12 mph	52.8 at 18 mph	35.7					24.8 at 32 mph		20.1	19.5		0.10	
Jet Industries Electra-van														
EV-106 Lead-acid batteries		69.8		46.4		40.1			25.8+	45.2	23.3		0.13	0.18
Special Test Vehicles														
Otis P-500 Van														
EV-106 Lead-acid batteries		29.4								21.1			0.22	0.30
Experimental Ni-Zn battery, NASA-LeRC		54.9								42.4				
Copper Development Assn. Copper Elec. Town Car														
EV-106 Lead-acid batteries						80.2						34.1		
Experimental Ni-Zn battery, NASA-LeRC						146.3								

INTRODUCTION

This report covers the initiation of a task to develop baseline test data which will allow ERDA to assess the state-of-the-art for electric vehicles. Such an assessment can be used (1) as a benchmark for measuring progress, (2) to help formulate standards and specifications for government purchase of electric vehicles, and (3) to determine areas where technology improvements are needed. Presented herein are the preliminary results of tests of five electric vehicles.

OBJECTIVE

The objective of the electric vehicle test task which NASA is performing for ERDA is to determine the performance of a representative sample of production, preproduction prototype, and experimental vehicles. Performance characteristics of special interest include range, acceleration, top speed, gradability and vehicle energy consumption, subsystem and component energy consumption and efficiency.

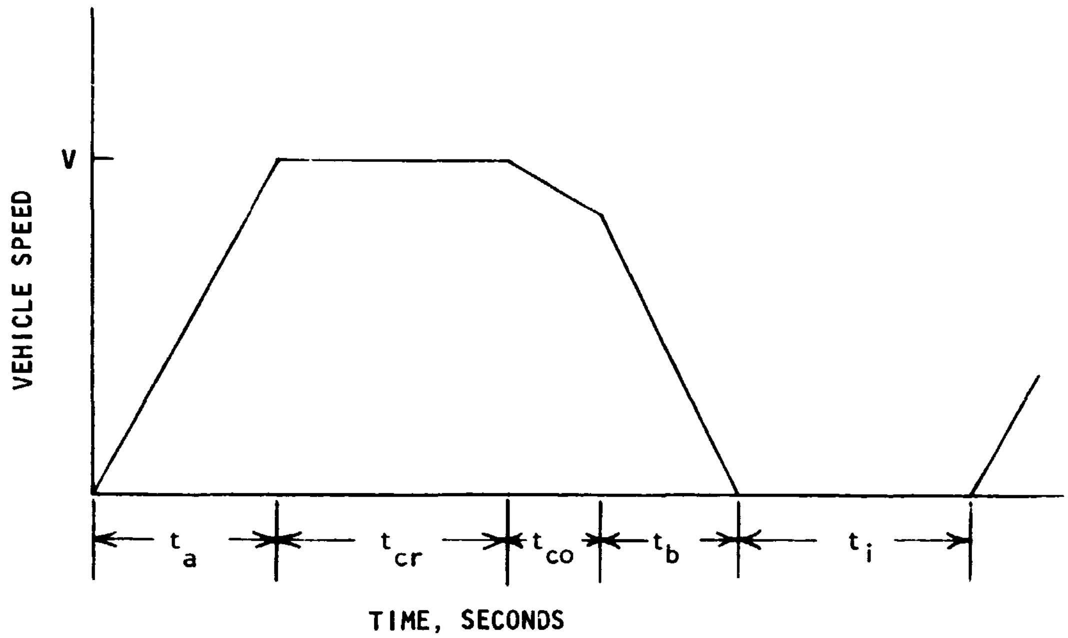
APPROACH

Performance tests on available electric vehicles are being conducted in accordance with selected procedures recommended in SAE Recommended Practice, Electric Vehicle Test Procedure - SAE J227a. The tests are being performed on commercial automotive test tracks. Currently, two tracks are being used: the DANA Corporation Test Track, a 3-lane, $1\frac{3}{4}$ mile, concrete track located at Ottawa Lake, Michigan, and the State of Ohio, Transportation Research Center Track, a 3-lane, $7\frac{1}{2}$ mile, concrete track located at East Liberty, Ohio.

Vehicles are being obtained by leasing, borrowing, or by direct purchase. In some cases the tests are carried out with the help of representatives of the vehicle manufacturer.

TEST PROCEDURE

Range Tests: Two types of range tests are described in the SAE J227a, constant speed tests and stop-and-go driving involving four different driving schedules. The constant speed tests are carried out at selected test speeds of



TEST PARAMETER	S.A.E. SCHEDULE A	B	C	D
MAX. SPEED, V, MPH	10	20	30	45
ACCEL. TIME, t_a, SEC.	4	19	18	28
CRUISE TIME, t_{cr}	0	19	20	50
COAST TIME, t_{co}	2	4	8	10
BRAKE TIME, t_b	3	5	9	9
IDLE TIME, t_i	30	25	25	25

Figure 1. - S.A.E. J227a - Driving Cycle Schedules

10, 20, 30, and 40 mph and maximum speed which are held constant within ±5 percent. The test is terminated when the vehicle speed falls below 95 percent of the chosen test speed. The test might be terminated earlier if another vehicle performance limitation is reached as may be specified by the vehicle manufacturer.

The stop-and-go-driving cycle tests shown in Figure 1 consist of an acceleration phase to a specified speed in a specified time period, followed by a cruise period at this speed, followed by coast, braking, and idle periods. The range is measured at the cycle period prior to the cycle in which the vehicle either ceases to meet the requirements of the selected driving schedule or reaching some other vehicle performance limitation specified by the vehicle manufacturer.

The data reported is to be the average of at least two test runs.

Acceleration Tests: This test determines the maximum acceleration of the vehicle on a level road with the battery at full charge and 40 and 80 percent discharged. At least two runs in opposite directions are required at each of three battery states-of-charge.

Gradability: Gradability is defined by the SAE as (a) the maximum grade on which the vehicle can just move and (b) the maximum vehicle speed which can be maintained on roads having different grades. The maximum grade capability of the vehicle is determined from tractive force measurements at speeds approaching 0 mph. By employing a load cell and knowing the weight of the vehicle, the maximum grade can be calculated from

$$\text{Percent grade} = 100 \tan\left(\sin^{-1}\frac{P}{W}\right)$$

where

P = tractive force in pounds

W = weight in pounds

The maximum vehicle speed on a specific grade is calculated from maximum acceleration performance of the vehicle.

$$\text{Percent grade at speed } V = 100 \tan\left(\sin^{-1} 0.0285\, \bar{a}_n\right)$$

where a_n is the average acceleration during time period t_{n-1} to t_n where vehicle speed increased from V_{n-1} to V_n. Therefore

$$\bar{a}_n = \frac{V_n - V_{n-1}}{t_n - t_{n-1}}$$

and the average speed at acceleration $\bar{a}_n$ is defined as

$$V_n = \frac{V_n - V_{n-1}}{t_n - t_{n-1}}$$

Vehicle Road Energy Consumption: This test is designed to determine the power and the energy consumption of the vehicle at various speed needed to overcome aerodynamic and rolling resistance. The road power required is reported as kilowatts and the energy consumption is reported as kilowatt-hours per mile. Coast-down tests from a normalized speed together with the equations below are used to calculate the power, P_n, and energy, E_n, requirements.

$$P_n \quad \text{kilowatts} = 5.06\times10^{-5}\, W \frac{V_{n-1}^2 - V_n^2}{t_n - t_{n-1}}$$

where W is the weight of the vehicle in pounds and t_n and t_{n-1} are the times in seconds required for the vehicle to reach speeds of V_n and V_{n-1} in miles per hour. The power thus calculated is reported at an average speed $\bar{V}$ calculated from

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

The energy consumption, calculated as kilowatt hours per mile, is obtained from the equation below.

$$E_n \quad \text{kilowatt hours per mile} = 9.07\times10^{-5}\, W \frac{V_{n-1} - V_n}{t_n - t_{n-1}}$$

where the units are as presented above and reported at an average speed $\bar{V}$.

INSTRUMENTATION

In developing an instrument package which would measure the essential parameters required in SAE J227a, it was decided to install a basic set of instruments in each vehicle which would satisfy our needs, while continuing the evaluation of various measurement techniques with the intention of updating our techniques to include more sophisticated equipment incorporating lessons learned from in-field operations. Preliminary evaluation of instrumentation techniques has shown potential problem areas; EMI noise from solid-state speed controllers and DC/AC inverters; reliability, mechanical vibrations and large variations in operating currents and voltage. With these problem areas in mind, several instruments were evaluated for use in the basic instrument package. The present system selection consists of:

(a) Two Honeywell 195 Electronik - two channel strip chart recorders, weighing about 30 pounds. These are easy to calibrate, hold calibration well, and have high input impedances; used for recording battery current and voltage, and vehicle speed and distance.

(b) Curtis Current Integrator SHR-C3; weighing about 10 pounds; used to measure charge and discharge battery capacity through a 500 amp/100 mv shunt.

(c) Tripp Lite 500 watt DC/AC inverter, weighing about 20 pounds; used to supply AC power to strip charts and current integrator.

(d) One or two 12-volt SLI batteries; 70 A-H weighing about 50 pounds each; used to power DC/AC inverter and supply 12-volt power where needed.

(e) Stop watch, Wakmann Brestling #917; used in SAE J227a stop/start cycle tests.

(f) Keithley Model 163 Digital Voltmeter weighing about 5 pounds; used to facilitate battery voltage monitoring during test runs.

(g) Nucleus Corp. Model NC-7 Precision Speedometer (5th wheel), with Electronic Pulser Model ERP-X1 for distance measurements, Pulse Totalizer Model NC-PTE, and Expanded Scale Speedometer, Model ESS/E and Programmable digital attenuator; the weight of the 5th wheel is approximately 30 pounds with the dash-mounted instruments weighing about 20 pounds.

(h) Hewlett-Packard Model 6920B Meter Calibrator, 0.2 percent accuracy on DC output, usable range 0.01 to 1000 volts.

All instruments are calibrated after installation in the test vehicle, and are recalibrated at the track between tests.

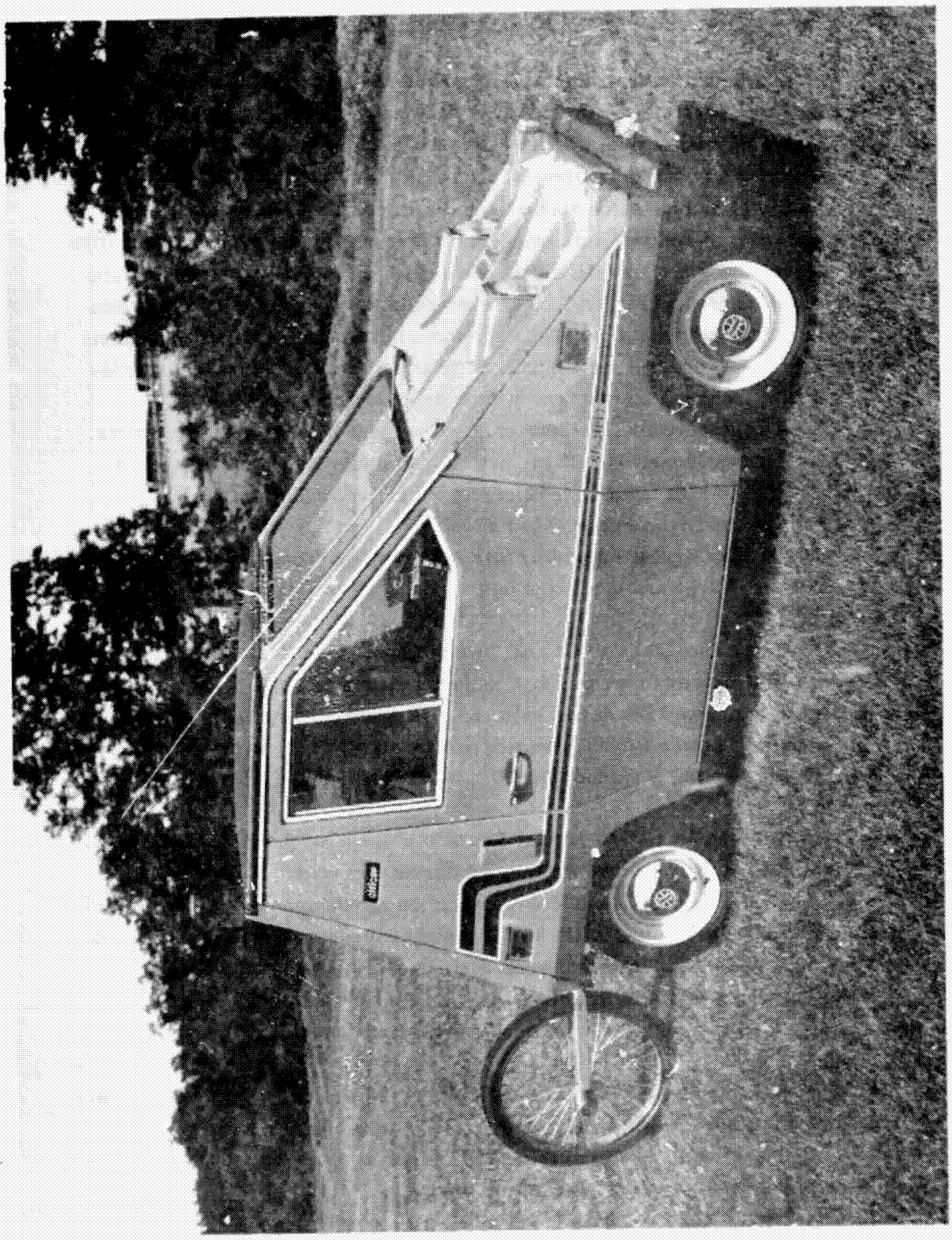


Figure 2. - Overall view of the "Citi-car" with 5th wheel attached.

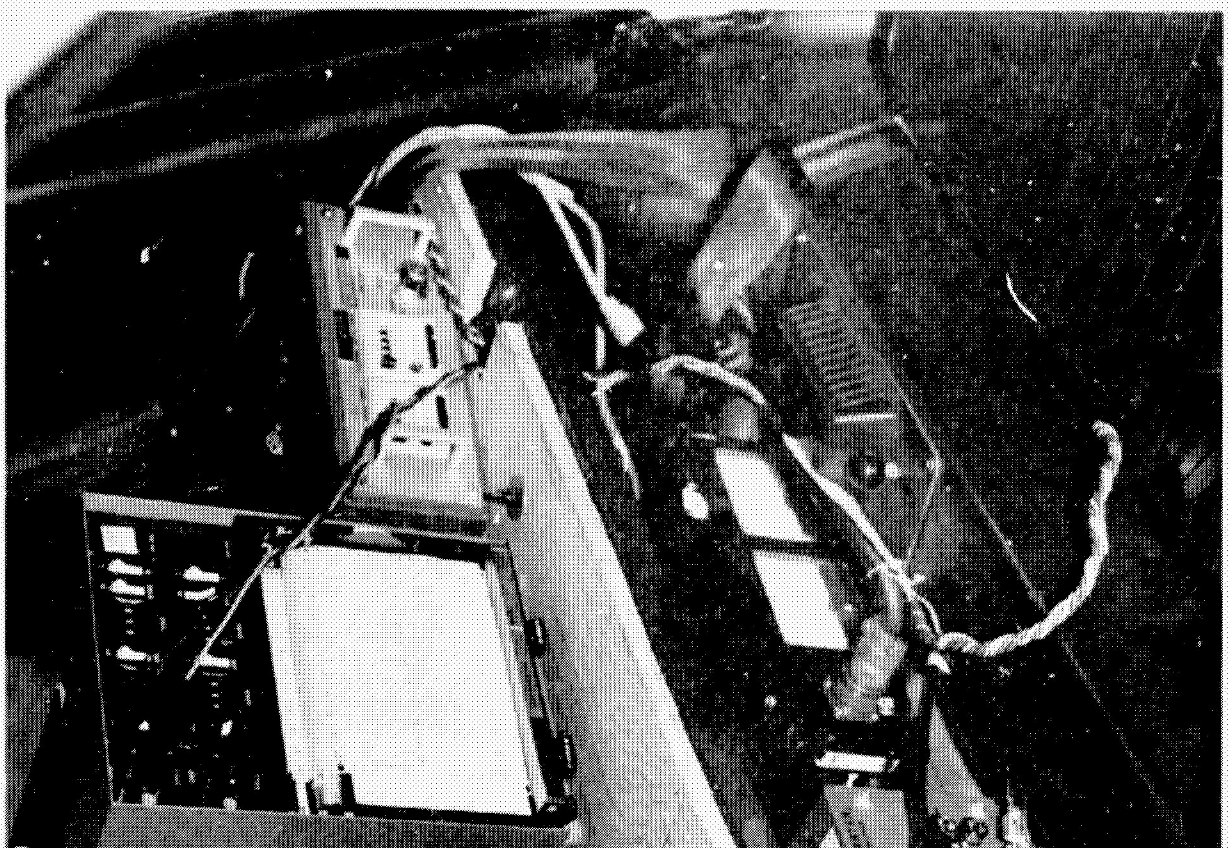


Figure 3.-- Recording instrument placement in the "Citi-car".

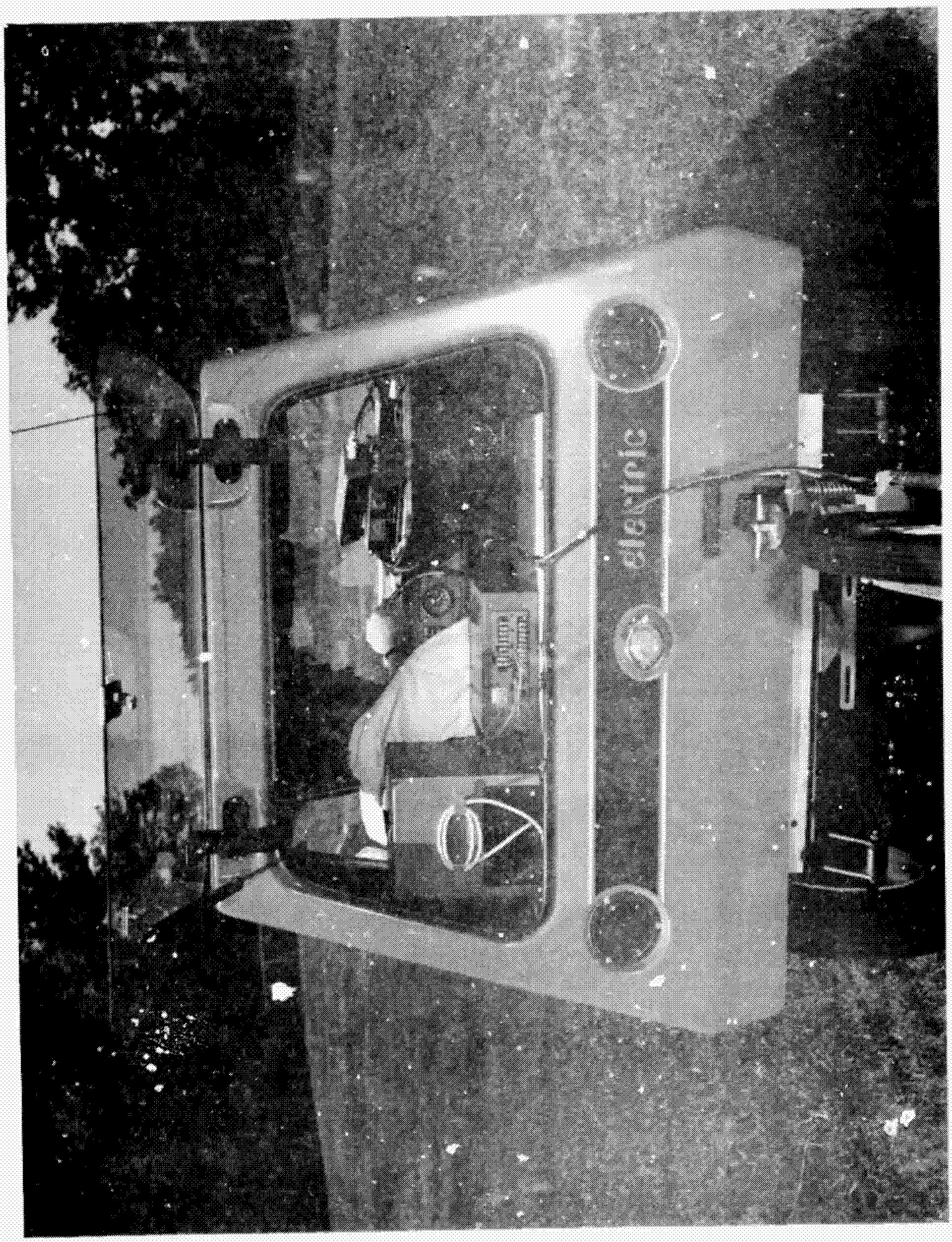


Figure 4. - Rear view of the "Citi-car" showing 5th wheel component placement.

This instrument package has demonstrated itself to be reliable and versatile for measurements required.

Figures 2, 3, and 4 show a typical instrumentation installation in a test vehicle. The subject shown is the Sebring-Vanguard, Inc.'s "Citi-car". The test results for this vehicle are presented in the "Test Result" section of this report.

Figure 2 shows an overall view of the Citi-car with the "5th wheel" attached to a rear-mounted bracket. On some vehicles without standard bumpers, a special bracket must be fabricated to properly secure the 5th wheel to the vehicle. This happened to be the case with the Citi-car. Figure 3 was photographed through the right-side door of the car looking to the rear. The upper left and center of the picture shows the two, 2-channel recorders mentioned above. The current integrator is visible in the upper right corner of the view. All three of these units just mentioned draw line power from the DC to AC inverter mounted on the lower shelf in the picture. The black box with two panel meters on its front is a junction box to distribute instrument power to various components in the system. The test meter in the picture was used to make occasional checks on the performance of the power supply system.

Figure 4 shows the rear of the Citi-car with the 5th wheel components in view to the right of the driver, on top of the dash. The two larger units mounted "piggyback" are the digital distance integrator (on top), and the analog speed indicator. The driver uses the expanded scale portion of the speed indicator to hold the vehicle speed steady on a fixed value when this is required. The smaller box on the right corner of the dash is a digital attenuator used to vary the count interval registered on the digital distance integrator (i.e., 10-ft intervals, 100-ft intervals, etc.).

TEST RESULTS

A total of five vehicles have been tested to date. In general, they followed the procedures described above. Adjustments were made in the test procedures to accommodate the limited time some vehicles were available, and to meet special purpose tests specified by the ERDA Program Office. Therefore, the test results are reported in two parts to clarify the different goals of the test operations. The first part, "Baseline Tests" include those tests on vehicles performed for general evaluation purposes (EVA car, Citi-car, and Jet Industires Van) while the second part, "Special Tests," covers tests on an Otis P500 Van and on the Copper Development Association's (CDA) experimental "Copper

Electric Town Car" to obtain comparative performance between standard EV-106 lead-acid batteries and a newly developed nickel-zinc battery.

Table 1 is presented as a summary of all the range test results obtained for the five test vehicles through August 1976. For the details behind these test results, the reader is referred to the detailed discussion which follows.

BASELINE TESTS

1. EVA Metro Sedan

Manufacturer: Electric Vehicle Associates
Parma, Ohio

. Vehicle Description: The EVA Metro is a four-passenger-four-door sedan converted to electric drive from a gasoline-powered Renault 12 vehicle. The conversion is somewhat unusual in that the manufacturer (EVA) chose to retain the entire stock drive train except for the gasoline engine. The electric motor drives the front wheels through the original equipment torque converter and automatic transaxle. The vehicles tested were early production models.

Specifications:

Vehicle A - Serial A-1178-9106843

Vehicle B - Serial R-1178-9111401

Size and Weight

- Length . . . . 174.0 in.
- Width . . . . 64.5 in.
- Height . . . . 56.6 in.
- Trunk Capacity . . . . 3 ft^3
- Road Clearance . . . . 5.5 in.
- Projected Frontal Area . . . . 20 ft^2
- Curb Weight . . . . 3150 lb.
- Gross Vehicle Weight . . . . 3750 lb.

Batteries (used for test)

- Main Traction

Manufacturer Exide Corp.

Type - lead-acid, golf cart, EV-106

Normal rating - 106 minutes at 75 amp (132.5 amp-hr), sixteen 6-volt units used in a 96-volt series string (10 units in the trunk, 6 units under the hood)

Weight - 1040 pounds

- Accessory

  Type - J.C. Penny Maintenance Free, and ESB Empire 12-Volt lead-acid SLI batteries in parallel

  Weight - approximately 100 pounds, total

Traction Motor

- Type - EVA series D-C
- Rating - 10 kilowatt at 3400 rpm
- Weight - 162 pounds

Controller

- SCR, 96 volt, electronic pulse type (Cableform, Inc.)

Transmission

- Type - original equipment torque converter and automatic transaxle.

Drive Axle

- Type - original equipment frontwheel drive transaxle with half shafts.
- Ratio - 3.65:1

Wheels

- Tires - Michelin 155 R-13 radial ply
- Tire pressure

  Front - 32 psi

  Rear - 32 psi
- Rolling distance

  Front - 69.3 in./rev.
- Wheel base - 96.0 in.
- Wheel track

  Front - 52.5 in.

  Rear - 52.5 in.

Battery Chargers

- Type - 96 Volt system - EVA Battery Marshall - 25 pounds

  - 12 Volt system - ESB Shure Start

Heater

- Type - Stewart Warner Gas Fired Hot Water
- Rating - 50,000 Btu - weight 85 pounds

Figure 5 shows the EVA Metro sedan as tested with the 5th wheel attached. The 16 traction batteries are mounted in this vehicle in two separate groups: six units under the front hood and 10 in the trunk compartment. Figure 6 shows the six batteries in the front of the car. The traction motor is out of sight under the battery group and part of the chopper control unit is visible at the

Figure 5. - Overall view of EVA Metro Sedan with 5th wheel installed.

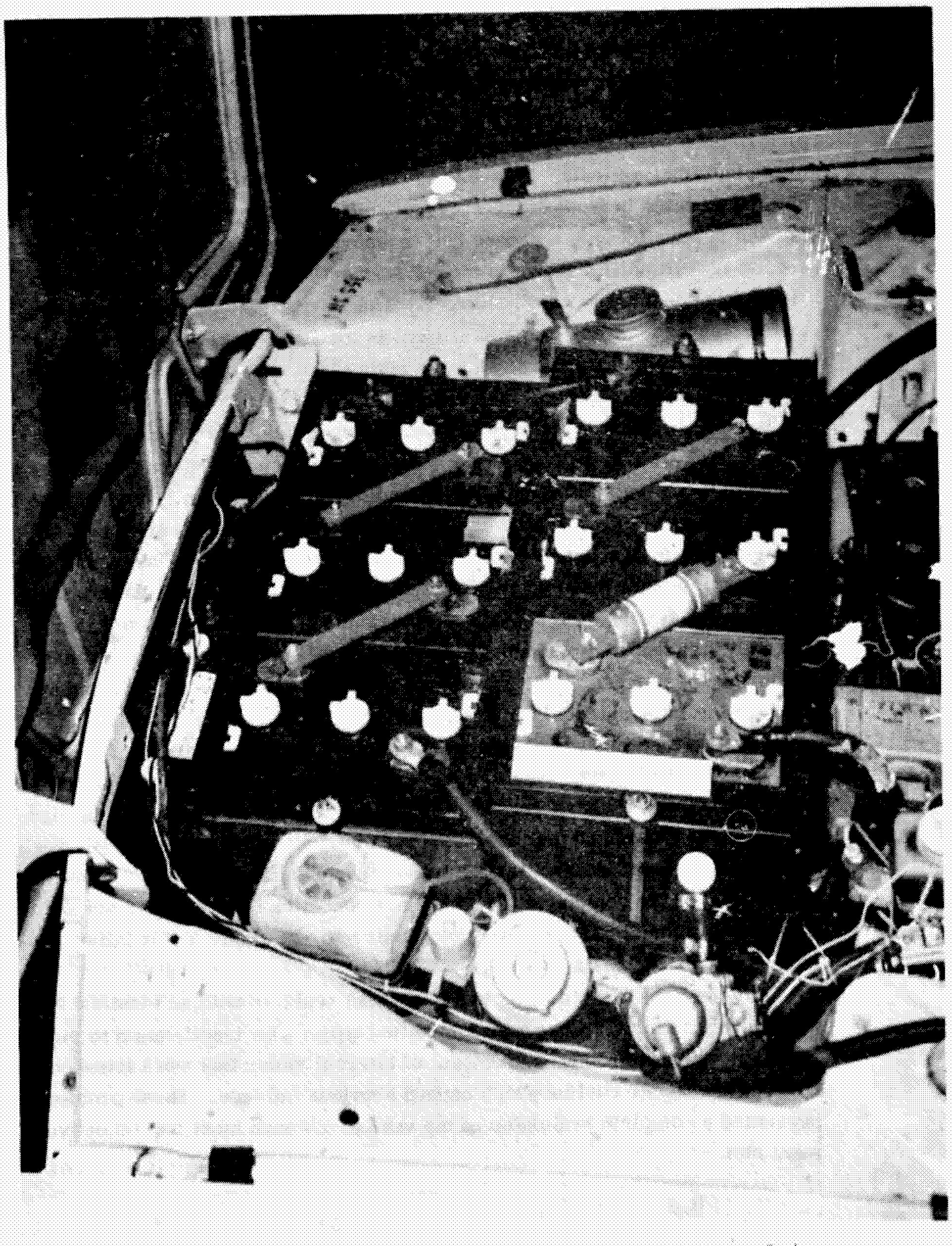


Figure 6. - Components in front compartment of EVA Metro Sedan.

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right-center edge of the picture. Note that the front of the car is at the left of the picture and the fuel tank for the gasoline heater can be seen between the batteries and the right front fender. The vacuum pump (electric motor driven) to operate the power brakes appears in the lower-right corner of the picture and one of the two battery line fuses is evident, mounted between two of the battery terminals. Notice the long, narrow-case 12-volt accessory battery mounted in front of the six traction batteries. This 12-volt battery is used in parallel with a second unit mounted in the rear of the car. This second 12-volt unit is shown in the upper-right corner of Figure 7 to the right of the on-board 12-volt charger. The 10 traction batteries are shown with the second battery line fuse evident in the front-left corner of the battery group. The on-board charger for the main traction batteries is located just inside the trunk and behind the main battery group.

Results: Tests on this vehicle were performed at the Transportation Research Center of Ohio test track. Because of the unusual conditions surrounding these tests, a chronological review is in order. In May 1975 ERDA requested the NASA-Lewis Research Center conduct a short series of tests on the EVA Metro sedan in order to determine whether its performance would be compatible with Washington, D.C. city traffic. Since only 1 week was available for testing, the manufacturer provided two vehicles (designated A and B in this report) to expedite the process. The constant speed cruising tests were performed at 25, 35, and 45 mph rather than the 20, 30, and 40 mph speeds later selected for baseline testing. ERDA purchased vehicle "B" along with two others and placed them in service in Washington.

In 1976, ERDA requested that a second series of tests be performed to repeat the first in order to see if the vehicles performance had deteriorated in use. It was intended that baseline data would also be obtained. Only vehicle B, driven 94[illegible] miles, was returned for evaluation. Due to previous committments for the vehicle, a limited time was available for these tests and the process was complicated by two motor failures. (A single motor failure occurred in the 1975 tests as well.)

For the first two failures, the motor was replaced with an identical type while after the third failure with a modified type. The modification to the motor (addition of external blower, removal of internal motor fan) were intended to correct inadequate cooling which caused previous failures. These problems prevented a complete evaluation of the vehicle although most test objectives were met.

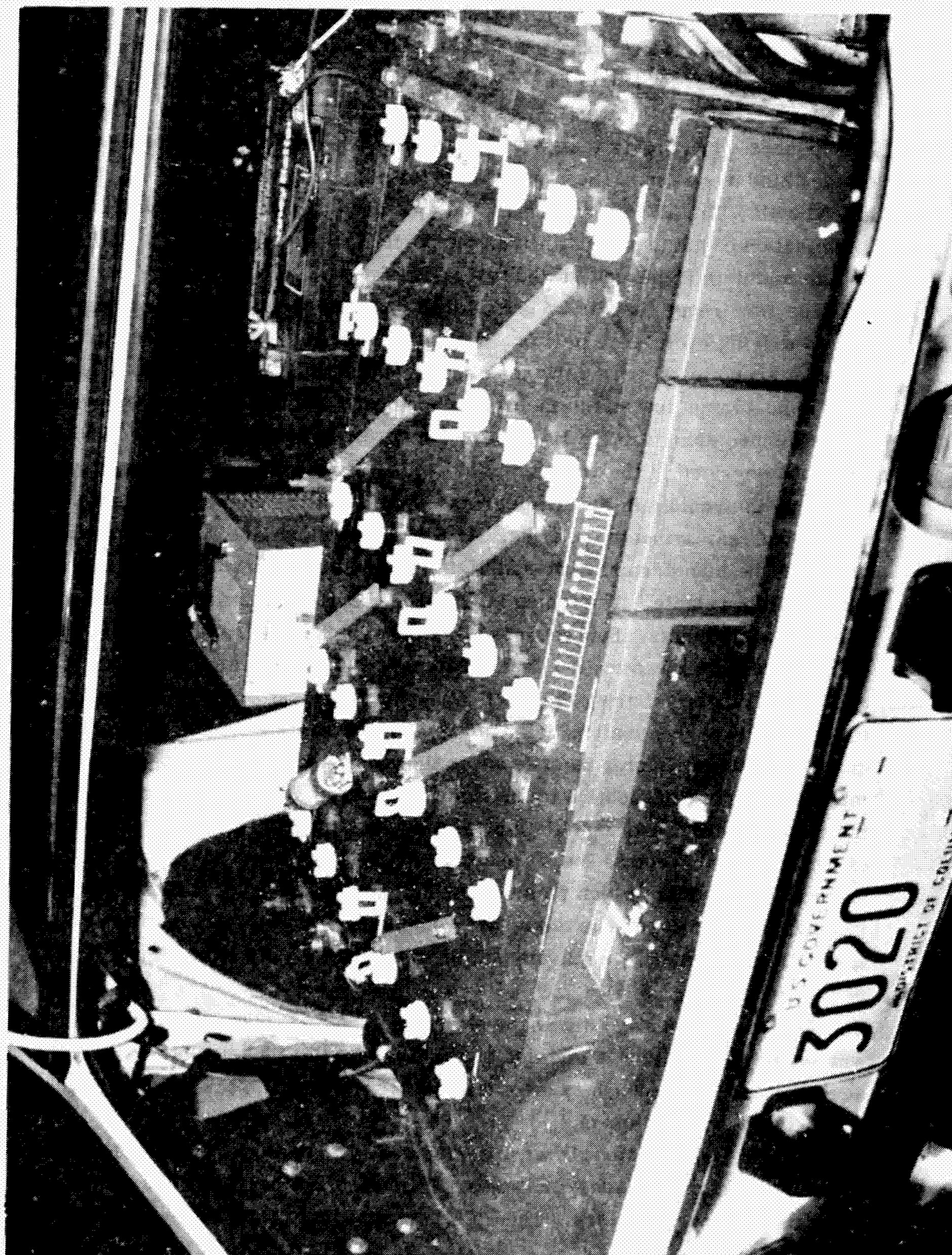

Figure 7. - Components in rear trunk compartment of EVA Metro Sedan.

Meteorology: During the 1975 test series the temperature ranged from 74° to 93° F and the wind varied from 5 to 15 mph. In the 1976 test series the temperature varied from 68° tc 81° F with a wind variation of 0 to 8 mph.

Range Tests: All range tests were performed at a vehicle test weight of 3750 pounds. SAE J227a test procedures were used except only single tests of each kind were run. The range was determined at speeds of 25, 35, 45, and 53 mph. The 53 mph range was the wide open throttle (WOT) condition. Termination of the test is defined as the point at which the vehicle is not able to maintain 95 percent of the test speed.

The 1975 range tests of 25 and 53 mph constant speed and 30 mph stop-and-go driving cycle were performed using vehicle A. The 35 and 45 mph constant speed tests were performed using vehicle B. Motor burnout between the 35 and 45 mph test led to motor replacement. The 1976 range tests were all performed using vehicle B. Motor number 2, installed during the 1975 tests and operated in the vehicle for 947 miles, failed during the first attempts at testing the vehicle in the 1976 series. Failure of the motor was due to a burned out rear armature bearing. At ERDA's request, the vehicle was returned to the manufacturer for installation of motor number 3, and a general tuning of the vehicle. The tuning included both battery charger and transmission adjustments. Subsequent to this the vehicle was tested on the 25 and 45 mph constant speed regime and the 30 mph "C" cycle region using the original batteries. During the WOT (53 mph) range test, motor number 3 failed. Failure was analyzed as being due to overheating caused by inadequate ventilation. Motor number 4 was then installed in vehicle B by the manufacturer. Modification to the vehicle at this time included removal of the motor internal fan, installation of an external blower, and heliarch welding of commutator. Vehicle B with motor number 4 was then used to complete the scheduled testing which included the 35 mph and WOT constant speed tests, the maximum performance tests, and vehicle dynamics tests. In order to meet ERDA's schedule requirements for the vehicle, only single tests were performed.

For the stop-and-go driving cycle range, the SAE J227a schedule "C" test was employed. This was dictated by the fact that the EVA vehicle could not accelerate rapidly enough to meet the requirements of the schedule "D" cycle (i.e., to 45 mph in 28 sec).

The 1975 series of tests were performed with a new set of batteries having less than 10 charge-discharge cycles. The manufacturer could not provide a more precise cycle history. The 1976 series of tests used batteries that were

TABLE 2. - EVA METRO SEDAN RANGE TESTS

TEST	RANGE, MILES	
	1975 Series*	1976 Series**
Range-at-steady-speed:		
25 mph	56.4 (Vehicle "A")	42.7 (Vehicle "B", Motor #3)
35 mph	34.0 (Vehicle B, Motor #1)	35.3 (Vehicle B, Motor #4)
45 mph	27.7 (Vehicle B, Motor #2)	28.5 (Vehicle B, Motor #4)
53 mph (W.O.T.)	28.0 (Vehicle A)	22.2 (Vehicle B, Motor #4)
Driving Cycle:		
Schedule C, 30 mph	21.6 (Vehicle A)	19.6 (Vehicle B, Motor #3)

*New Batteries

**Used Batteries (1 year, 947 mile service), vehicle charger and transmission adjusted during year, motor replacement as indicated.

in service for 1 year and had undergone an unknown number of charge-discharge cycles since that data was not available from ERDA.

Results of the range tests are presented in Table 2. Inasmuch as two vehicles were used and vehicle conditions were not the same because of motor replacements, battery use, and charger and transmission adjustments made during the in-service period, the data is not readily comparable. No data are reported in the 1976 series with new batteries. An inspection of the test data showed that incipient motor failures produced unusually high battery current drains.

Braking Tests: Although the SAE J227a requirements do not cover braking capabilities, these vehicles were intended for use in city traffic where emergency braking would be required. Braking tests performed in 1975 and again in 1976 showed that the vehicles were able to stop in 135 to 139 feet from 50 mph and in 47 to 48 feet from a speed of 30 mph. These results are consistent with the values of 54 to 57 feet at 30 mph and 142 to 150 f .t at 50 mph suggested by DOT Motor Vehicle Safety Standard 105-75. Please note, however, that no attempt was made to follow the MVSS 105-75 procedure.

Acceleration Tests: Maximum acceleration tests were conducted in 1975 using vehicle A with 0 percent discharge batteries only. In the 1976 test series the maximum acceleration tests were performed using vehicle B, motor number 4, with its year-old batteries at full charge and at 40 and 80 percent discharge. The state of charge of the batteries was determined through use of the on-board current integrator which measures the capacity removed from the battery. The vehicle was run at the maximum cruise speed as specified in sections 2.8 and 3.2.4 of SAE J227a, until the desired capacity had been removed. This data is presented in Figure 8. It should be noted that the 40 percent discharged batteries performed as well as the fully charged batteries. The acceleration profile as a function of speed is shown in Figure 9.

Gradeability: The maximum acceleration data presented in Figure 9 was used to calculate the speeds the vehicle could maintain on various grades. Results of these calculations are shown in Figure 10 for the 1975 and 1976 tests. As seen, the maximum grade the vehicle is able to climb at a speed of 5 mph with a fully charged battery was 25 percent for the 1975 test and dropped to 21 percent in the 1976 test. The latter value fell to 15 percent when the battery was 80 percent discharged. At a speed of 40 mph the vehicle climbing capability is reduced to less than a 3-percent grade with a fully charged battery and zero when the battery was 80-percent discharged.

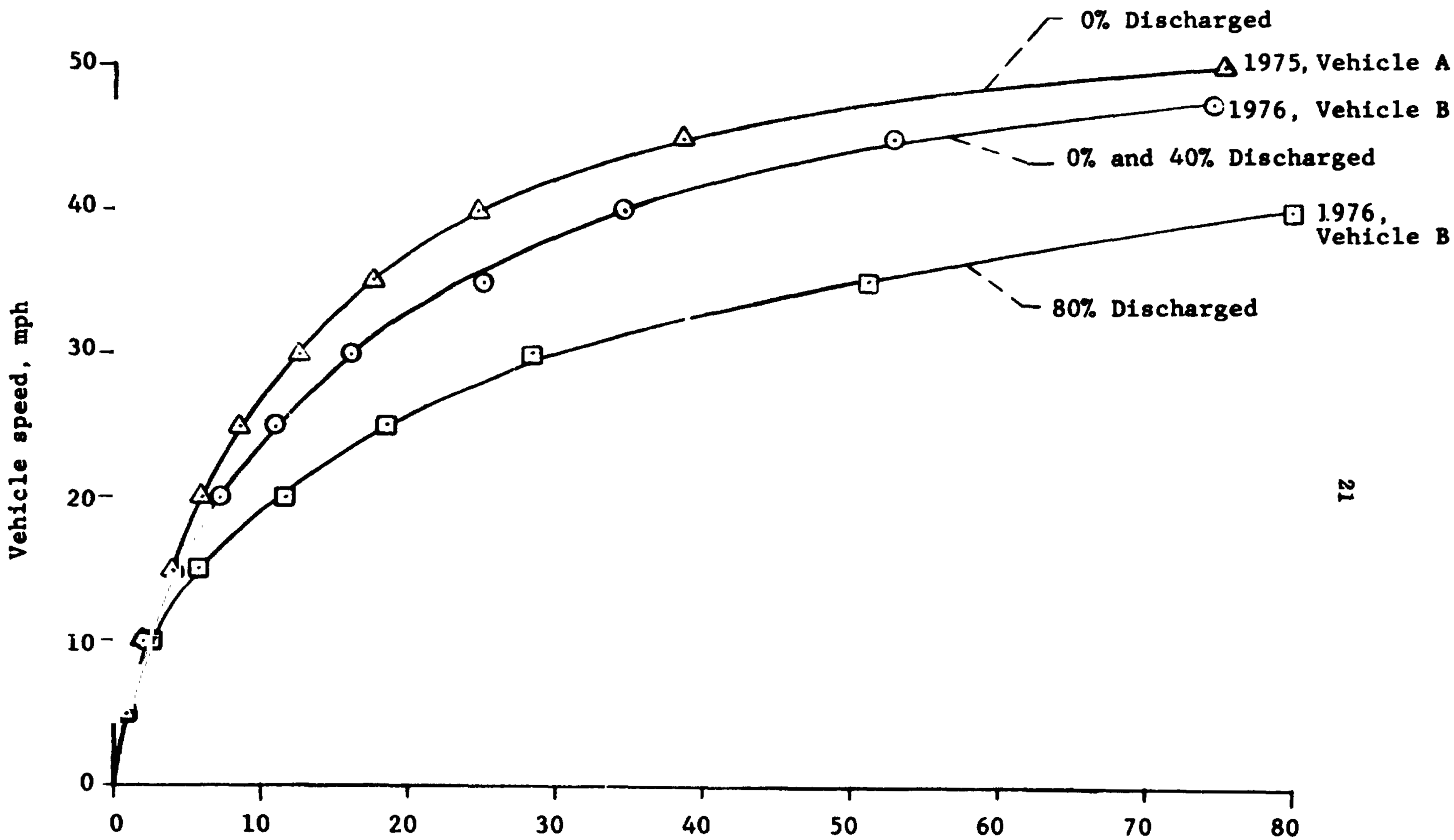

Figure 8. - Acceleration characteristics of EVA Metro-sedan

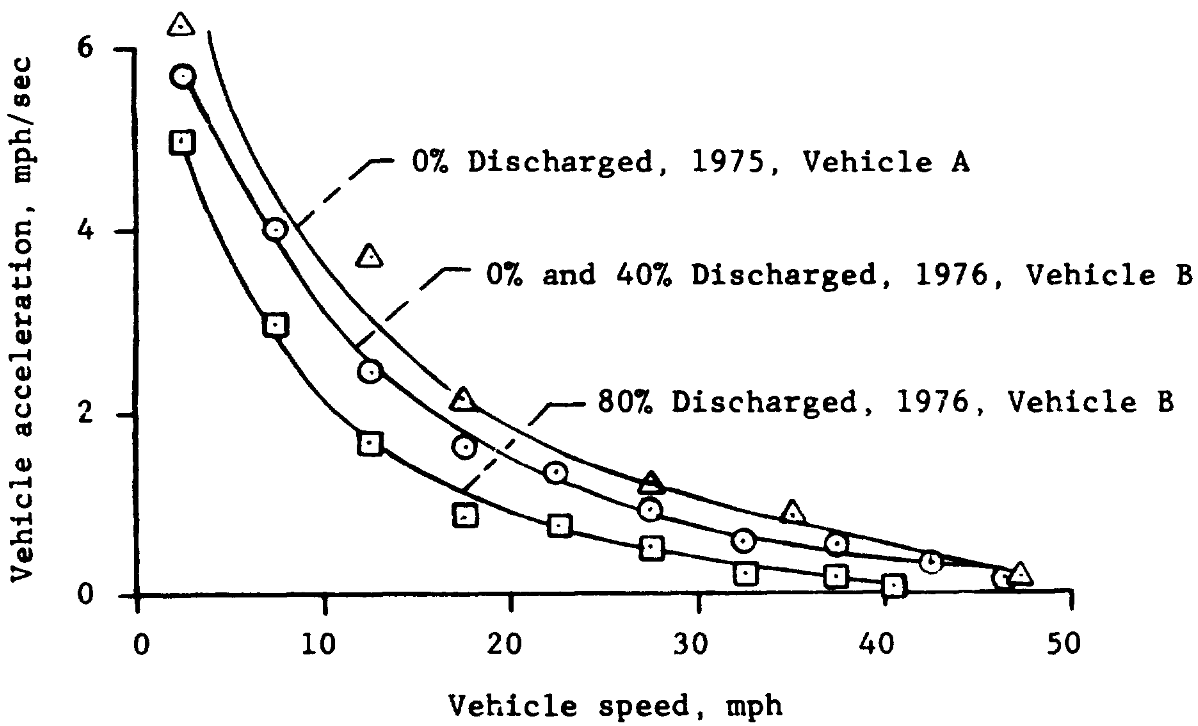

Figure 9. - Vehicle maximum acceleration as a function of vehicle speed for EVA Metro-sedan

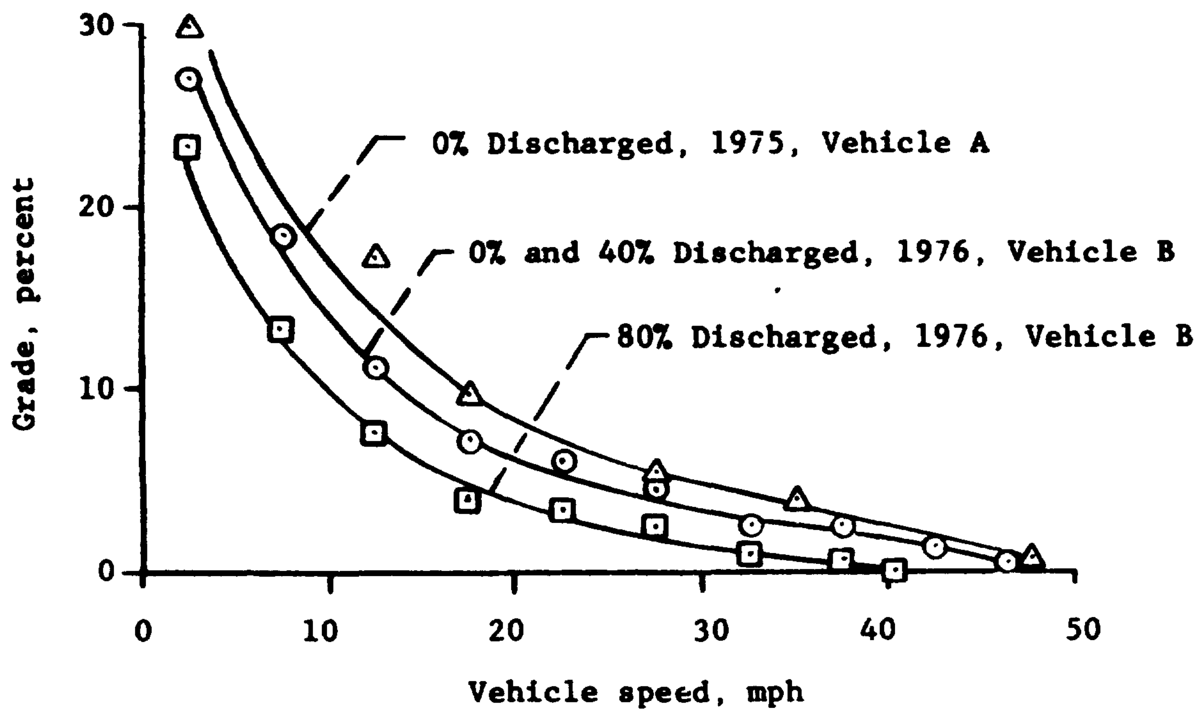

Figure 10. - Gradeability of EVA Metro-sedan

Energy Consumption: The energy consumption of the vehicle is determined from coast-down tests. The SAE recommends that the coast-down test should be performed with the drive components disconnected from the wheels. Results of the tests would then give the specific energy and power consumption for the vehicle with a 100-percent efficient drive train and charging system. Since detaching the drive shaft from the wheels was impractical, the coast-down tests were run with the transmission in neutral. Therefore, the only losses other than aerodynamic and chassis are the losses of the differential and a small portion of the transmission.

Results of the coast-down tests are shown in Figure 11 as speed versus time. The results for the 1975 vehicle A test and the 1975 vehicle B test are identical within ±2.5 percent for the speed range from 20 to 40 mph. Whether this result is significant cannot be determined since the variability between vehicles is not known and vehicle A was not available for retesting in 1976. The vehicle test weight in both cases was 3750 pounds. Through the use of equations presented in the SAE J227a recommended test procedures, the road energy and power consumption was calculated. This data is presented in Figures 12 and 13. As can be seen the vehicle traveling at 25 mph requires 3.0 kilowatt of power and consumes 0.12 kilowatt-hour/mile to overcome aerodynamic, chassis and some drive train loads. At 40 mph the power and energy consumption increases to 7.4 and 0.19, respectively.

Energy Economy: The SAE J227a requires a determination of the input charger energy necessary to recharge the batteries after the various range tests. A typical residential type kilowatt-hour meter was used to measure the charger input energy in both the 1975 vehicle A and 1976 vehicle B tests. Charge termination criteria used were two-fold: (a) specific gravity of all cells of at least 1.280, (b) concommitent drop in charge current to about the 5-ampere level. Energy economy data is presented in figure 14 for the constant speed tests. As can be seen, there is a difference in the 1975 tests when compared to the 1976 tests. One possible explanation is the use of two different types of EVA chargers, adjusted differently.

By comparing data presented in Figure 12 to that in Figure 14 the efficiency of the charger/battery/speed controller/transmission combination may be determi ᐨ. At a speed of 25 mph the efficiency is calculated to be between 21 and 25 percent while at 40 mph it increases to between 32 and 35 percent.

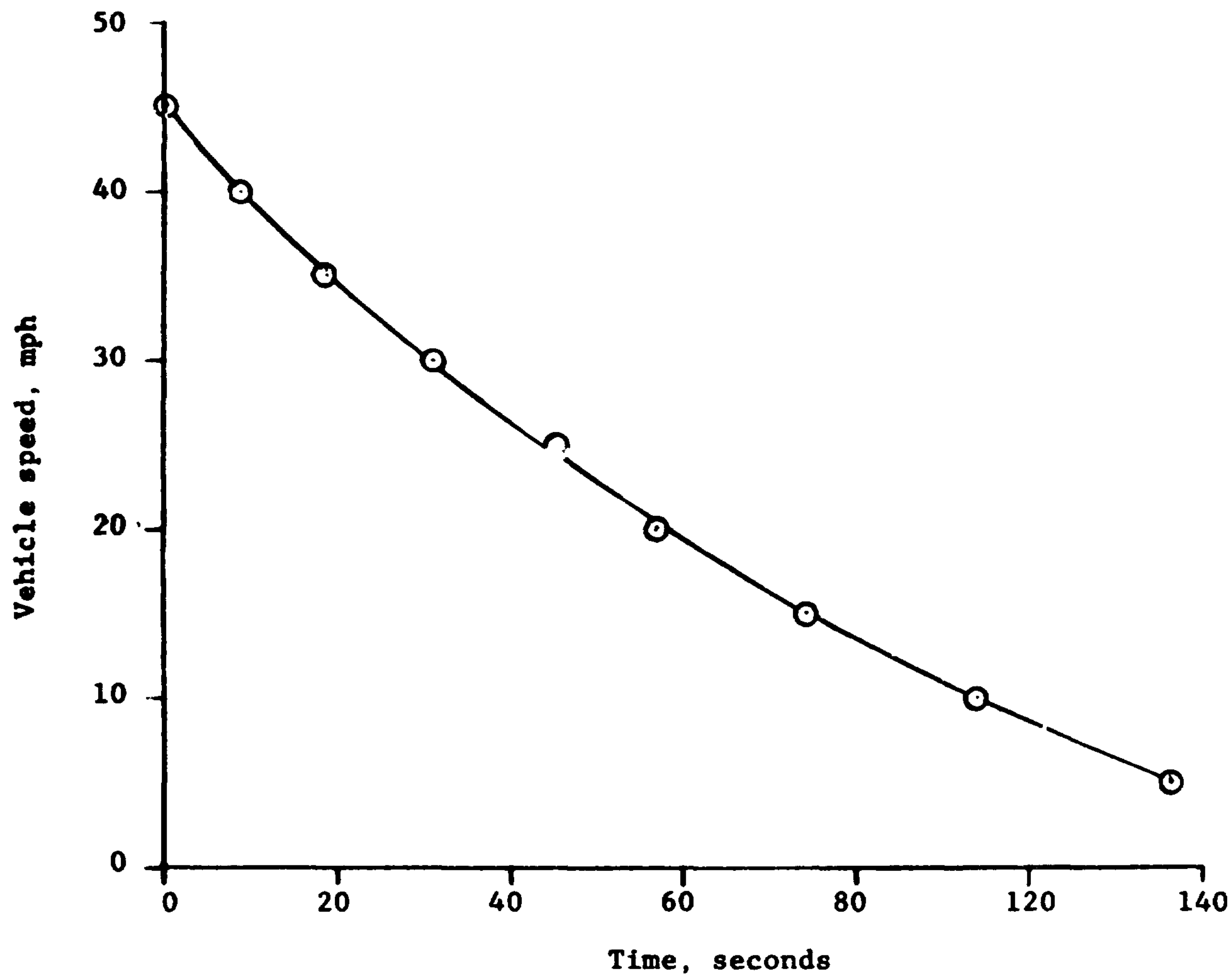

Figure 11. - Vehicle speed as a function of time during coasting for EVA Metro-sedan: Vehicle A (1975 test) and Vehicle B (1976 test)

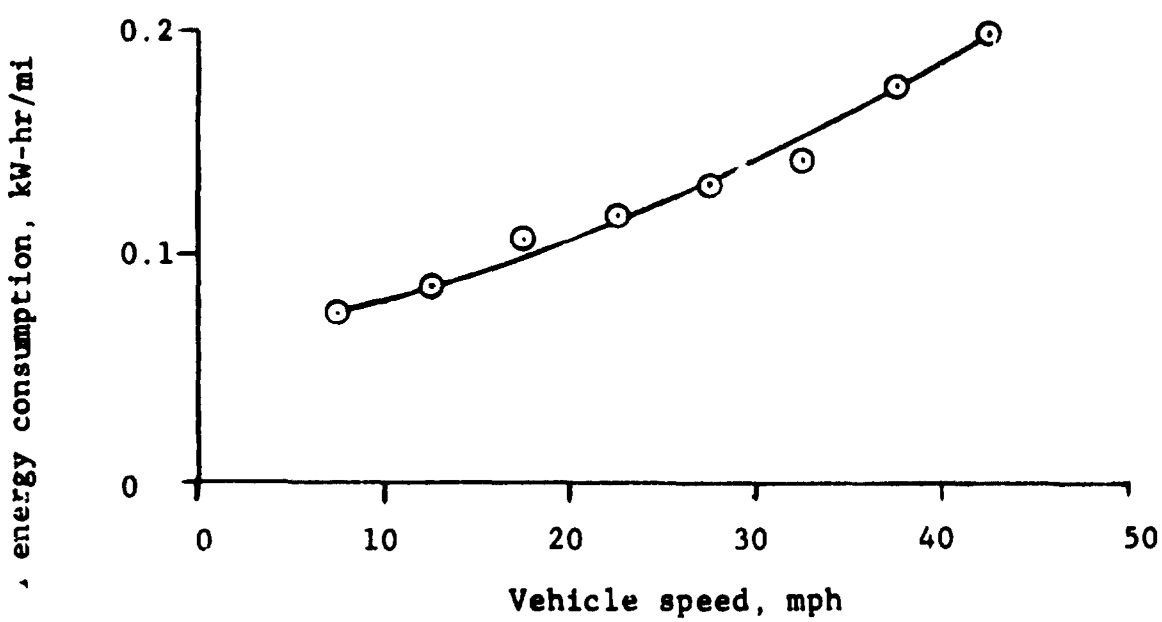

Figure 12. - Road energy consumption as a function of vehicle speed for EVA Metro-sedan: Vehicle A (1975 test) and Vehicle B (1976 test)

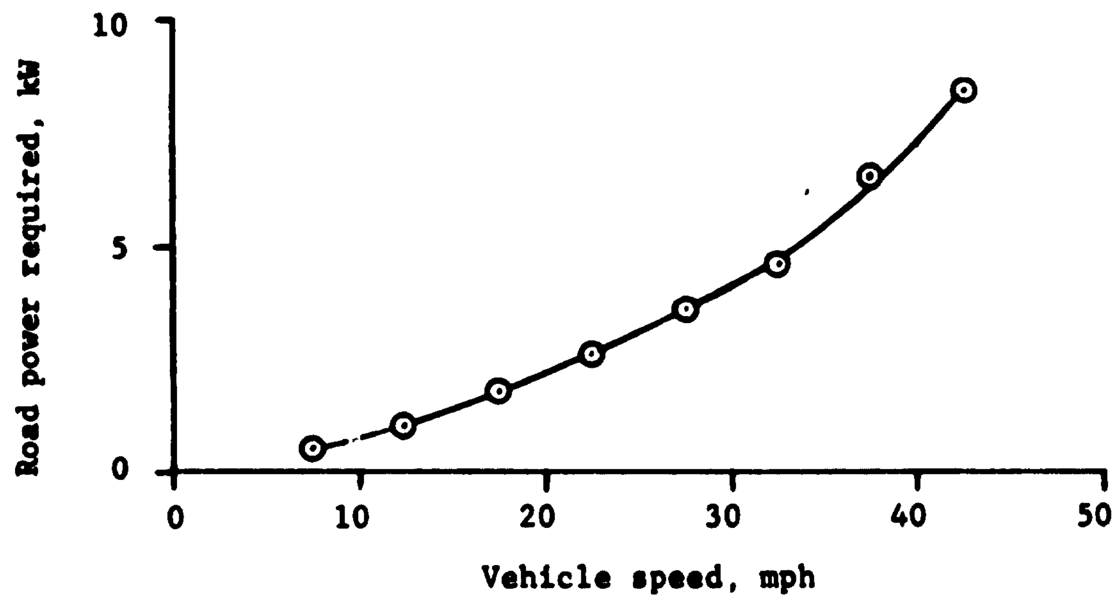

Figure 13. - Road power required as a function of vehicle speed for EVA Metro-sedan: Vehicle A (1975 test) and Vehicle B (1976 test)

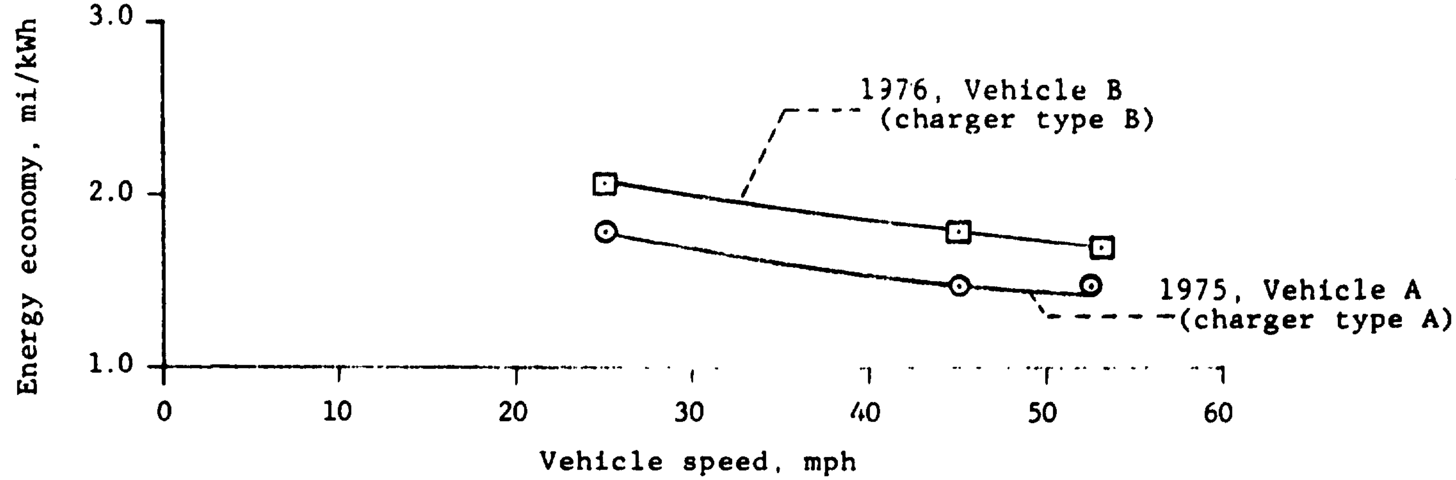

Figure 14. - Energy economy as a function of vehicle speed for EVA Metro-sedan

2. Sebring-Vanguard Citi-Car

Manufacturer: Sebring-Vanguard, Inc.
Sebring, Florida

Vehicle Description: The Citi-car is a small, two-passenger vehicle intended for general passenger and delivery service in a low-speed city driving pattern. According to the manufacturer, the 1300-pound curb weight vehicle has a maximum range of about 50 miles per charge with a top speed of 38 mph with only an operator on board. The vhicle tested for this report was one of two purchased by the Energy Research and Development Administration (ERDA) for evaluation. The test unit was a mid-1976 production Model 111-DW.

Specifications:

Serial Number - 606 SR 20 10A

Size and Weight

- Length . . . . 94.0 in.
- Width . . . . 54.8 in.
- Height . . . . 59.5 in.
- Load Space Size,
  Manufacturer's Spec. (room for 4 or 5
  average grocery bags behind passenger seat) . . 12 ft^3
- Road Clearance . . . . 7.3 in.
- Projected Frontal Area . . . . .17.1 ft^2
- Curb Weight . . . . 1300 lb.
- Gross Vehicle Weight . . . . 1750 lb.

Batteries (used for test)

- Main Traction
  Manufacturer Exide Corp.
  Type - lead-acid, golf cart, EV-106
  Normal rating - 106 minutes at 75 amp (132.5 amp-hr), eight 6-volt units used in a 48-volt group
  Weight - 520 pounds
- Accessory
  Type - Gould Lead-acid, SLI, 12-volt, 37 amp-hour
  Weight - 37 pounds

Traction Motor

- Type - General Electric series DC
- Rating - 6 hp at 4100 rpm

Controller

- Two-voltage level contactor battery switching controller with auxiliary resistor in series for starting.
- Three-step controller actuated by accelerator positions
  - 1st step - 24 volts with series Nichrome Resistor
  - 2nd step - 24 volts
  - 3rd step - 48 volts
- Electric reverse switch on dash

Transmission (none used)

Drive Axle

- Type - rear wheel drive with motor mounted on differential
- Ratio - 6.83:1

Wheels

- Tires - Goodyear, 4.80×12 2-ply nylon
- Tire pressure - 50 psi
- Standing drive wheel radius - 9.7 in.
- Rolling distance, rear drive wheels, 61.7 in./rev
- Wheel base, 65.5 in.
- Wheel track
  - Front - 43.25 in.
  - Rear - 44.50 in.

Onboard Charger

- Type - Lester Manufacturing Co.
- Rating - Charges 12- and 48-volt system; 115 VAC input; 8- to 10-hour charge

Photographs of the Citi-car appear as Figures 2, 3, and 4, to be found in the Instrumentation section of this report. No photographs of the drive train components were obtained but the main traction batteries are mounted under the passenger seat; the motor is flange-mounted to the differential housing; and the accessory battery is mounted under the dash in front of the passenger's seat.

Results: Only single tests of each kind were run. All tests were conducted at a vehicle test weight within 2 percent of 1750 pounds, the gross vehicle weight rating (GVWR) of the car. At this test weight, however, the vehicle's maximum speed was only 32 mph.

Because of the type of speed controller used on the Citi-car, a change in the test procedure was instituted. The controller operates in three distinct steps depending on accelerator position; (1) 24 volts with resistor, (2) 24 volts without resistor, or (3) 48 volts. For each step, there is a single equilibrium

TABLE 3. - SEBRING-VANGUARD CITI-CAR RANGE TEST RESULTS

Test	Meteorology	Range, miles	No. of cycles
Range-at-steady speed	Wind speed, temp.		
12 mph	6-7 mph, 75° F	42.6	--
18 mph	6-8 mph, 78° F	52.8	--
25 mph		35.7	--
32 mph (WOT)	7-9 mph, 82° F	24.8	--
Driving Cycle Range			
Schedule B, 20 mph	Calm, 73° F	20.1	95
Schedule C, 30 mph	Calm, 75° F	19.5	56

speed which the vehicle will reach and hold. If the operator wishes to hold an intermediate speed, he must move the accelerator pedal and continually switch between the controller positions which bracket the desired speed. This makes holding the speed constant somewhat difficult. It was decided therefore to modify the test procedure to use the equilibrium speeds for each step, and one intermediate speed in the upper range. The test speeds which resulted and corresponding controller positions are:

1st step - 12 mph
2nd step - 18 mph
2nd and 3rd step - 25 mph
3rd step - 32 mph (WOT)

Range Tests: Results of the various range-at-steady-speed tests as shown in Table 3 with appropriate meteorology data. As can be seen, the 18 mph test gave a range of 52.8 miles while the 12-mph test gave a lower range of 42.6 miles. This reduction in range is primarily due to the fact that appreciable energy was consumed in the series resistor used in the first step. At 25 mph, the vehicle was able to travel 35.7 miles while at 32 mph (WOT) the vehicle traveled only 24.8 miles.

Cycle Test: Two cycle tests were performed, the "B" and "C" cycle as specified in SAE J227a. It was judged that these two cycles were within the capability of this vehicle. Results of these tests are reported in Table 3. As can be seen the vehicle was able to complete 95 "B" cycles while traveling 20.1 miles and also complete 67 "C" cycles while traveling a distance of 19.5 miles.

Braking Test: The Citi-car was accelerated to 30 mph and the brakes were rapidly applied for maximum braking just short of wheel "lock-up". From this speed the vehicle required 59 to 60 feet in which to stop. These values are close to those suggested in DOT Motor Vehicle Safety Standard 105-75 which is 54 to 57 feet from 30 mph. However, no attempt was made to follow the DOT procedure, so no claim can be made as to the validity of the measurement.

Acceleration Tests: The maximum acceleration data for the Citi-car shown in Figure 15 indicates that the fully charged and 40-percent discharged battery values are almost identical while the 80-percent discharge values fall slightly below the full charge curve. The acceleration as a function of vehicle speed, shown in Figure 16, shows the acceleration with fully charged and 40-percent discharged battery to be equal, while the 80-percent discharged battery curve shows a somewhat lower acceleration characteristic.

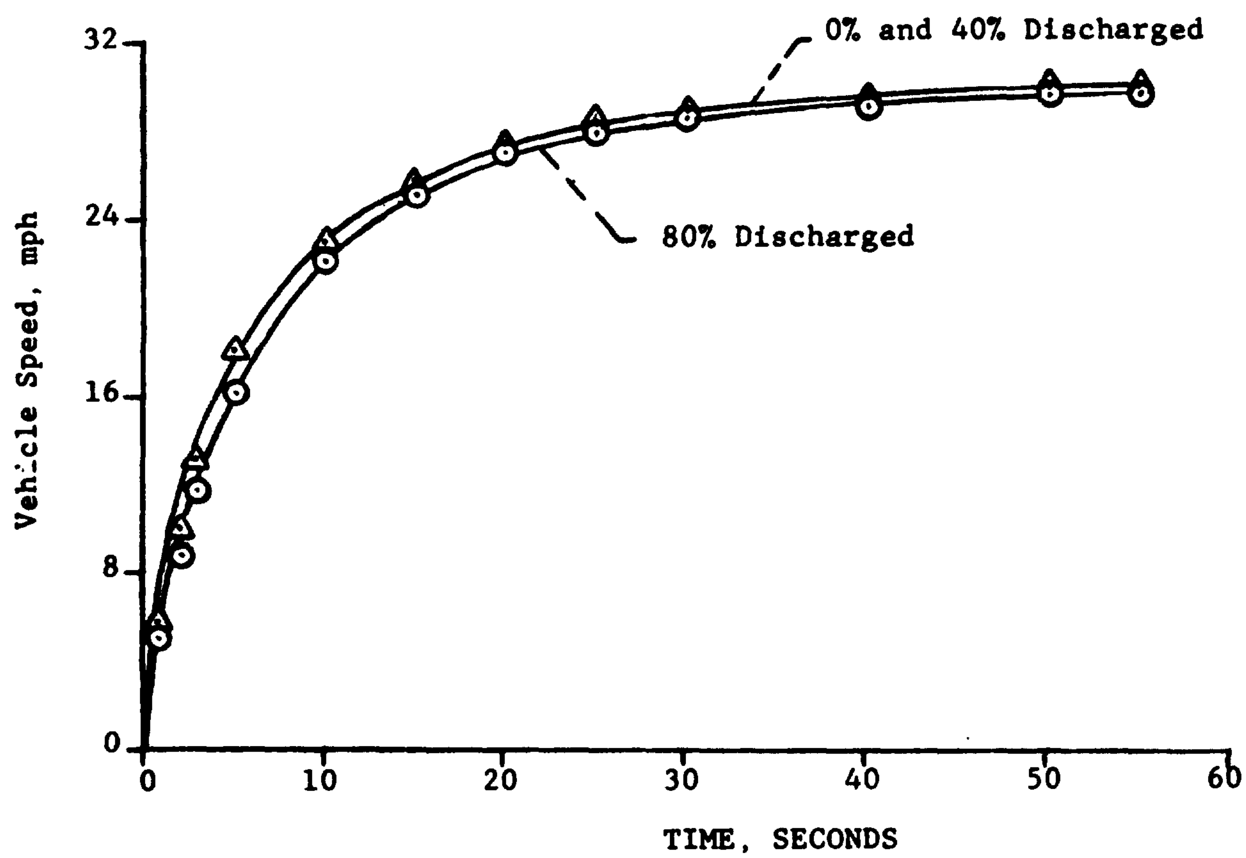

Figure 15. - Acceleration Characteristics of Citi-Car

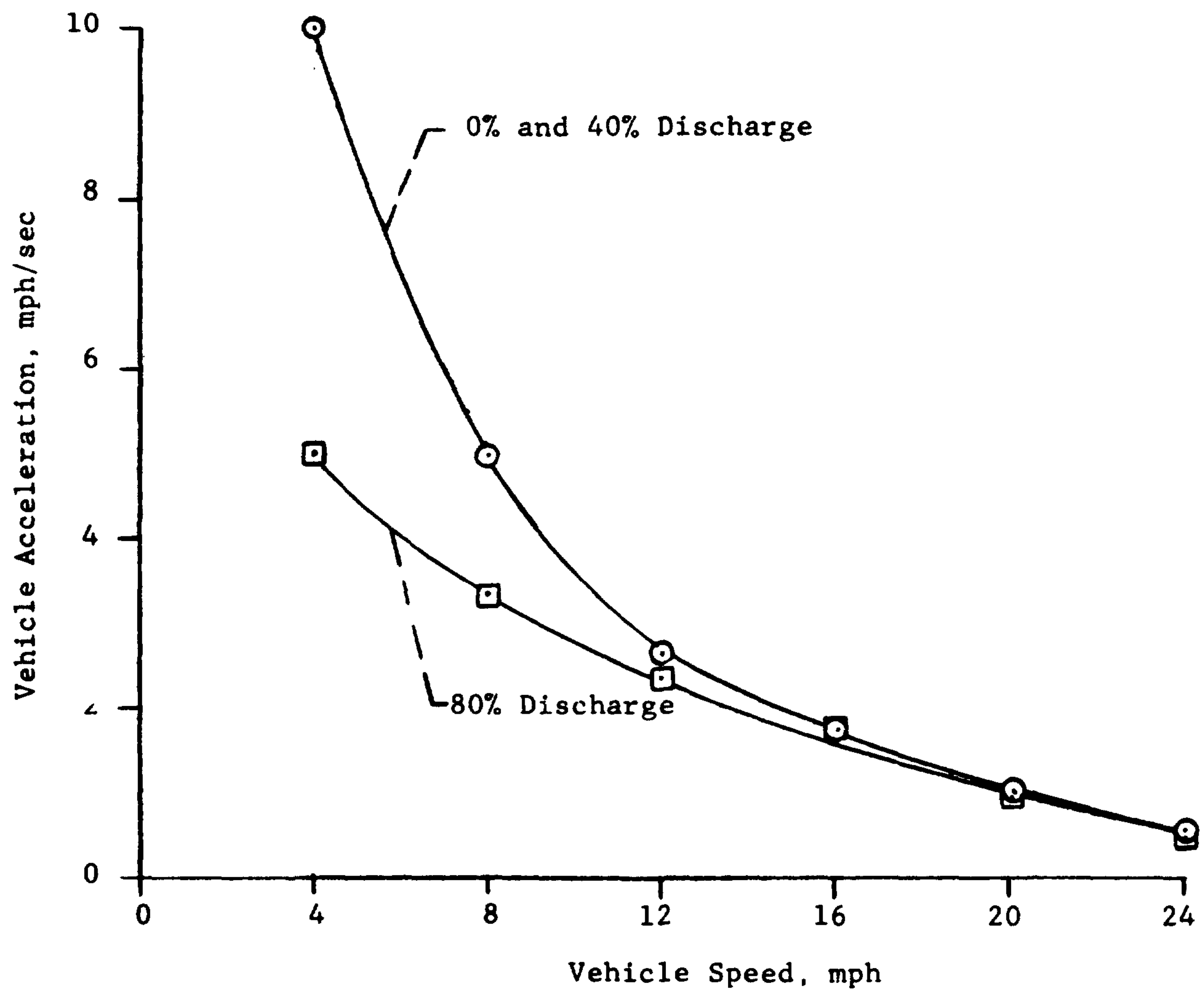

Figure 16. - Vehicle maximum acceleration as a function of vehicle speed for Citi-Car.

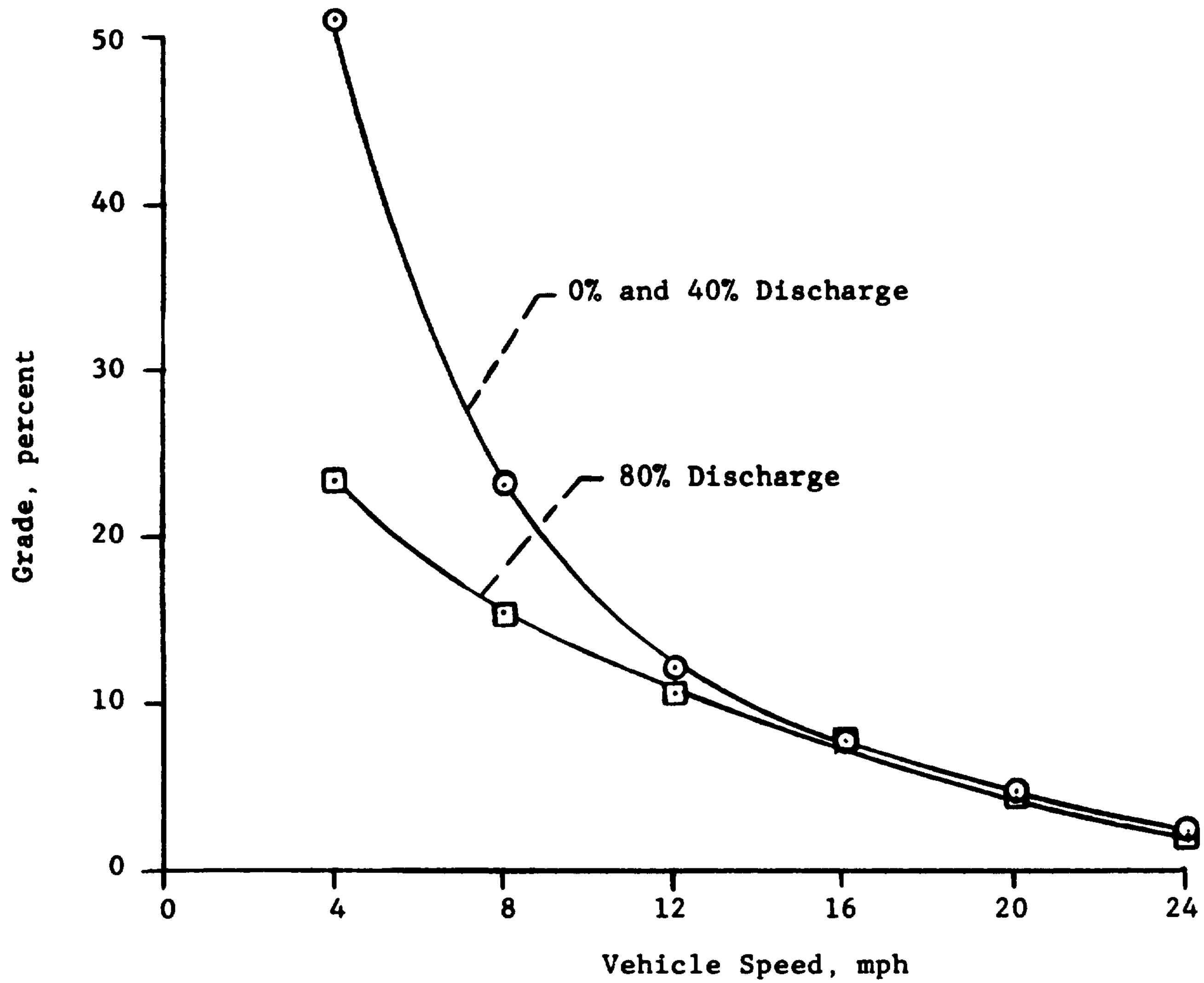

Figure 17. - Gradeability of Citi-Car.

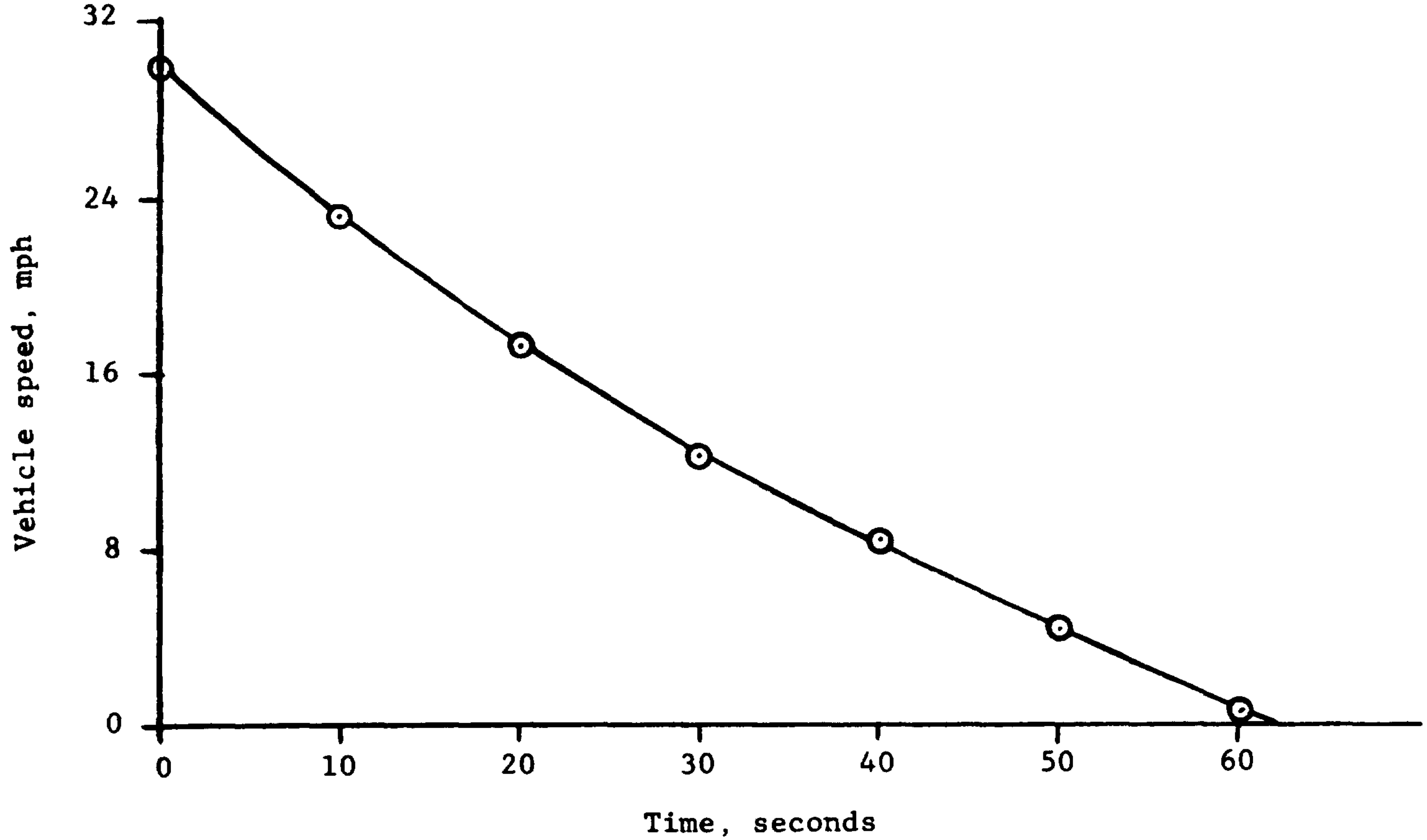

Figure 18. - Vehicle speed as a function of time during coasting for Citi-Car.

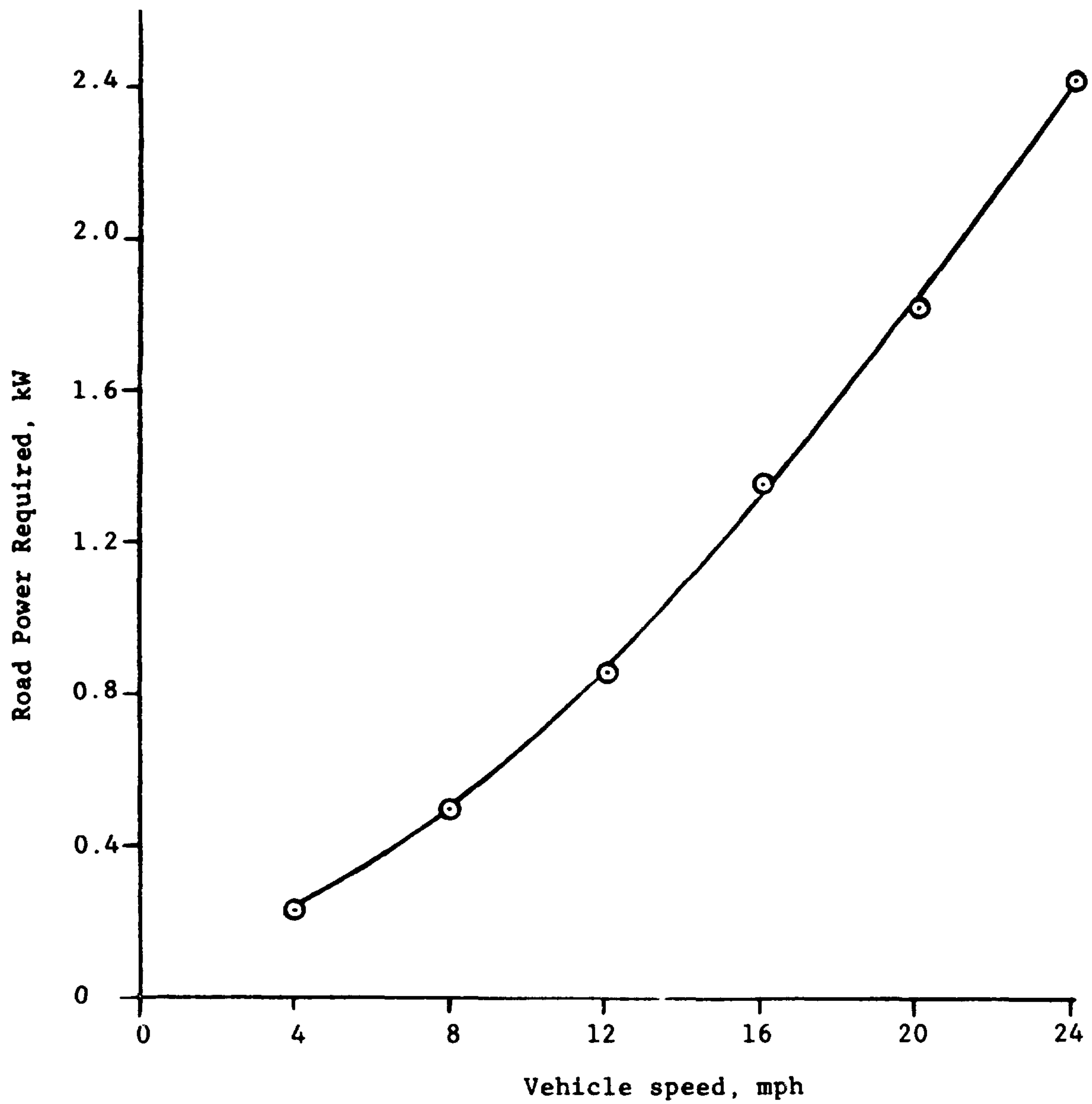

Figure 19. - Road power required as a function of vehicle speed for Citi-Car.

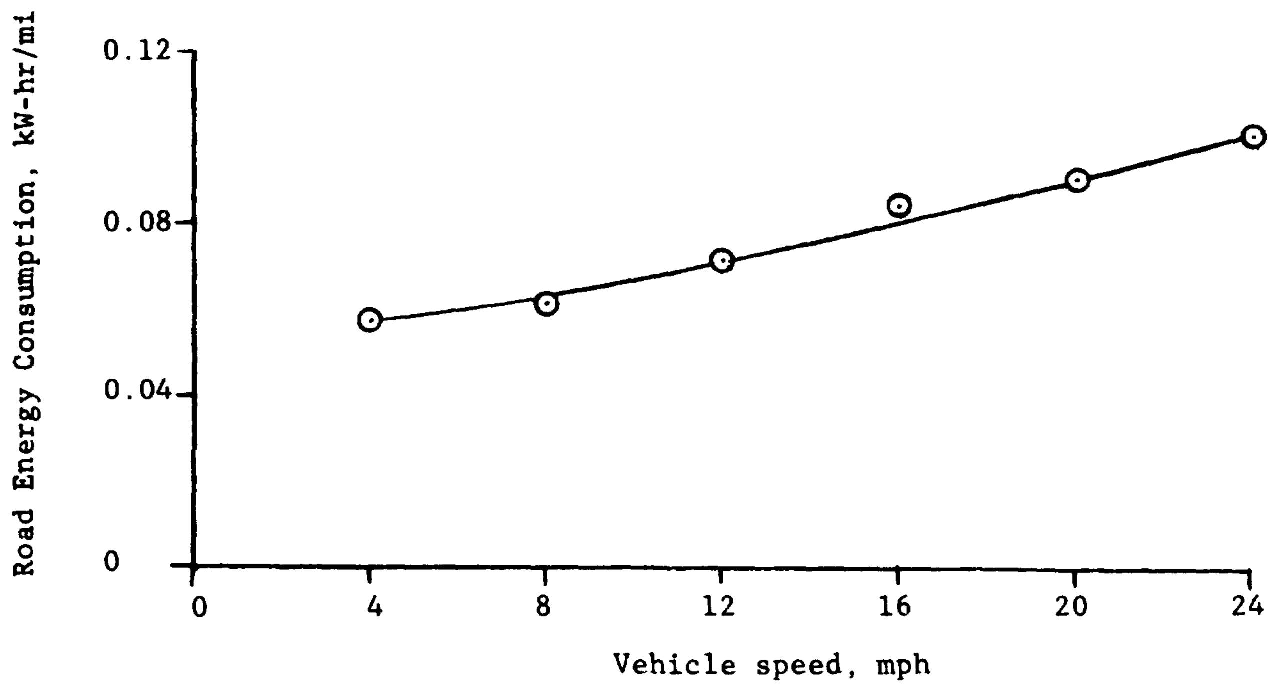

Figure 20. - Road energy consumption as a function of vehicle speed for Citi-Car.

Figure 21. - Overall view of Jet Industries Inc. Electra Van with 5th wheel attached.

Gradeability: Gradeability curves in Figure 17 show the maximum grade the Citi-car can negotiate at a given speed. As can be seen, at a low speed of 4 mph the grade this vehicle can negotiate varies from 25 to 50 percent depending on the state-of-charge of batteries. At 24 mph, the grade is reduced to 2 or 3 percent and is not a strong function of battery state-of-charge.

Energy Consumption: The Citi-car's road energy consumption data was obtained from a coast-down test from the vehicle's top speed. At top speed the car's accelerator was released, the direction selector switch was moved to neutral, and the vehicle was allowed to coast to a complete stop. The results of this test is shown in Figure 18. From this data the road power and road energy requirements for this vehicle were calculated and are presented in Figures 19 and 20. As can be seen from these figures the road power and energy requirements at a speed of 4 mph is 0.26 kilowatt and 0.057 kilowatt-hour/mile, respectively, while at 24 mph the power requirement rises to just over 2.4 kilowatts while the energy requirement rises to 0.10 kilowatt-hour/mile.

3. Jet Industries Electra-Van

Manufacturer: Jet Industries
North Seattle, Washington

Vehicle Description: The Jet Industries "Electra-Van", see Figure 21, is a converted Sabaru minivan in the 500-pound payload class. The compact vehicle has "bench" type seating in front for a driver and one passenger. There is seating space in the rear over the battery box for two additional passengers, or the rear seat back can be removed to utilize the full load space for cargo.

Specifications:

Serial Number - None

Size and Weight

- Length . . . . 121.9 in.
- Width . . . . 51.0 in.
- Height . . . . 63.5 in.
- Cargo Bed Length . . . . 63.0 in.
- Cargo Bed Width . . . . 43.3 in.
- Road Clearance . . . . 7.3 in.
- Projected Frontal Area . . . . 18.4 ft^2
- Curb Weight . . . . 2500 lb.
- Gross Vehicle Weight
  (500-lb payload + 150-lb driver) . . . . 3150 lb.

Batteries (used for test)

- Main Traction
  - Manufacturer Exide Corp.
    - Type - lead-acid, golf cart, EV-106
    - Normal rating - 106 minutes at 75 amp (132.5 amp-hr), fourteen 6-volt units used in an 84-volt group
    - Weight - 910 pounds
- Accessory
  - Type - Lead-acid SLI, 12-volt, 80 amp-hr

Traction Motor

- Type - Baldor Series DC, forced air ventilation
- Rating - 10 hp at 3500 rpm
- Weight - 168 pounds

Controller

- SCR, 84 volt, electronic pulse type (Cableform, Inc.)

Transmission

- Type - 4-speed synchromesh forward, 1-speed reverse
- Ratios
  - 1st - 3.80:1
  - 2nd - 2.05:1
  - 3rd - 1.32:1
  - 4th - 0.89:1
  - Rev - 3.88:1

Drive Axle

- Type - rear wheel drive transaxle with half shafts
- Ratio - 4.395:1

Wheels

- Tires - Bridgestone K663
  - 5.00 to 10 4 P.R., bias ply
- Tire pressure
  - Front - 40 psi
  - Rear - 42 psi
- Standing drive wheel
  - Radius - 0.25 in.
- Rolling distance, front and rear - 60.2 in./rev
- Wheel base - 68.25 in.

- Wheel track

  Front - 44.25 in.

  Rear - 44.75 in.

Charger

- Type - Jet Industries on-board charger for 84- and 12-volt system
- Rating - 110 volt - 30 amp, 44 pound, 8 hours required

Figure 22 shows a view of the van's drive train components from the rear of the vehicle. The traction motor is evident at the center-rear of the van. The under-the-floor compartment right-forward of the motor contains the vehicle's on-board charger (charger ventilation blower is visible in the upper portion of the compartment). To the left and forward of the traction motor is located the 12-volt accessory battery. The 14 unit, 84-volt traction battery case is in view forward of the raised rear deck of the load space. The SCR controller is contained in the space behind the traction battery case just forward of the rear axle. A better view of the batteries and the controller is provided in Figure 23 taken through the right side cargo door of the van.

Results: Tests on the Jet Industrie's Electra-Van were somewhat complicated by the fact that the vehicle has four forward speeds available plus a reverse gear. However, no clutch is used in the system. Although one could shift gears at speed, gear shifting was didficult and it did not appear to be good normal practice to follow. Thus, for a given test, a gear ratio was selected and held fixed for the test duration. The criterion for gear selection was to choose a ratio which would permit maximum motor speed during the test without exceeding the rated motor speed of 3500 rpm. Only single tests of each kind were run.

Range Tests: Results of the range tests are presented in Table 4. At the 40-mph vehicle speed, a range of 40.1 miles was attained. Similarly, at 30 mph, a range of 46.4 miles was achieved while at 20 mph, the range of 69.8 miles.

For the cycle testing, schedules A, B, and C were driven. During the 30-mph cycle test (schedule C) the van traveled 23.3 miles and for the 20-mph cycle test (schedule B) it reached 45.2 miles. For the schedule A cycle test (10 mph) the vehicle was on the track for over 15 hours and more than 1350 cycles. At this time (1:50 a.m.) it was noted that the charge on the 12-volt accessory battery of the vehicle was very low and operation would have to be concluded. Also, there were heavy areas of fog and deer around the track and continued operation was becoming hazardous. Therefore, after 25.8 miles of operation in this mode, the 10-mph cycle test was ended. It is estimated that another 2 to 3 miles (100 to 200 cycles) could have been achieved if conditions had remained satisfactory.

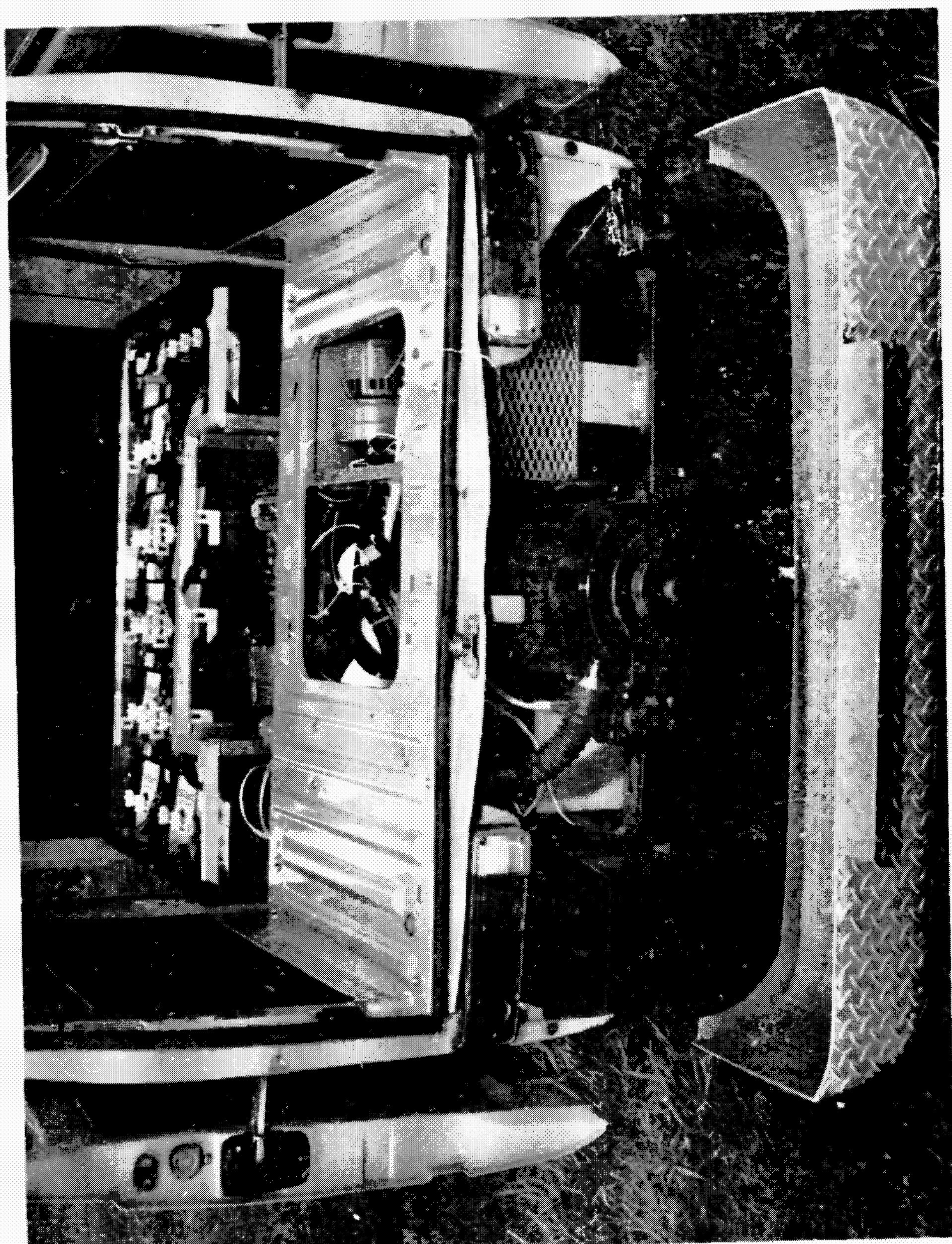

Figure 22. - Rear view of Jet Industries Inc. Electra Van showing drive train components.

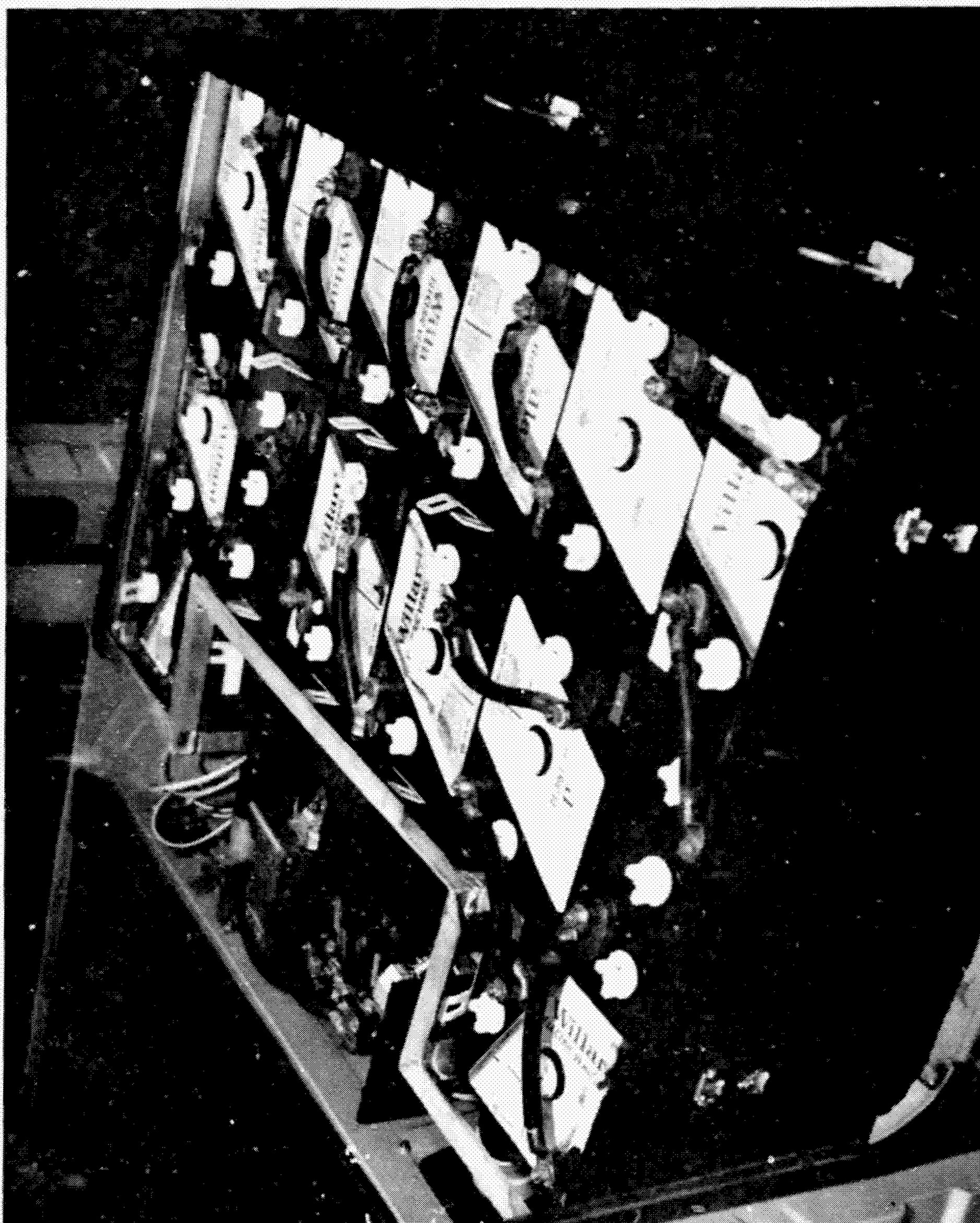

Figure 23. - View through right cargo door of Jet Industries Inc. Electra Van showing traction batteries and motor controller.

TABLE 4. - JET INDUSTRIES ELECTRA·VAN RANGE TEST RESULTS

METEOROLOGY: All tests with the electra-van were performed at temperatures in the range 71° F to 81° F and with winds from calm to 10 mph.

Test	Gear Ratio Used	Range, miles	No. of Cycles
Range-at-steady-speed:			
20 mph	2nd	69.8	---
30 mph	3rd	46.4	---
40 mph	4th	40.1	---
Driving cycle range:			
Schedule A, 10 mph	1st	25.8 + (see text)	1353 + (see text)
Schedule B, 20 mph	2nd	45.2	219
Schedule C, 30 mph	3rd	23.3	67

Braking Tests: In maximum braking tests the Electra-Van vehicle required a distance of 114.0 feet to stop from an initial speed of 45 mph. From a speed of 50 mph the van required a stopping distance of about 140 feet. These results are consistent with the requirements of DOT Safety Standard 105-75 which are 150 to 169 feet from 50 mph. However, since the DOT procedure was not followed, no claims can be made for the validity of this result.

Acceleration Tests: Acceleration tests were attempted using all four forward gears in the Electra-Van but the results of the test in first gear, at least, are in doubt. The Jet Industries representative (driver during the performance tests) concentrated on keeping the traction motor at a safe speed, and did not use the vehicle's maximum potential in first gear. It should be noted that the motor reaches rated speed (3500 rpm) at about 12.5 mph in first gear, and the representative's concern about the motor's safe speed was well founded. Indeed, one problem with this particular vehicle is the ease with which the motor could be put into an overspeed condition in the lower speed gear ratios. A tachometer was available in the vehicle with which to monitor motor speed. At this time the first gear acceleration data is not reported but the tractive force of the vehicle was obtained in first gear and was used (see later section) to compute first gear gradeability.

Figures 24, 25, and 26 show the Electra-Van's acceleration capability in second, third, and fourth gear, respectively. For convenience, Table 5 shows acceleration times as a function of state-of-charge and gear selection.

In Figure 24, for second gear, note the small effect of battery state-of-charge. In Figures 25 and 26, at higher speeds when the battery power required becomes large, the effect of battery state-of-charge becomes noticeable.

Gradeability: Because of some doubt that the lower gear accelerations represent the true maximum capability of the Electra-Van, only the vehicle's first gear gradeability will be presented as determined from a tractive force test.

The tractive force test was performed by towing a second vehicle with the test van - the two vehicles being connected by a standard 3000 psi range load cell. The Electra-Van was operated at a speed of between 2 and 3 mph during this test. The state of battery charge between 9 and 80 percent discharge was not significant in this test. The maximum tractive force in first gear was found to range from 1256 to 1337 pounds with an average value of 1294 pounds. The resulting first gear gradeability of the vehicle was found to be a 46-percent grade in the 2- to 3-mph speed range.

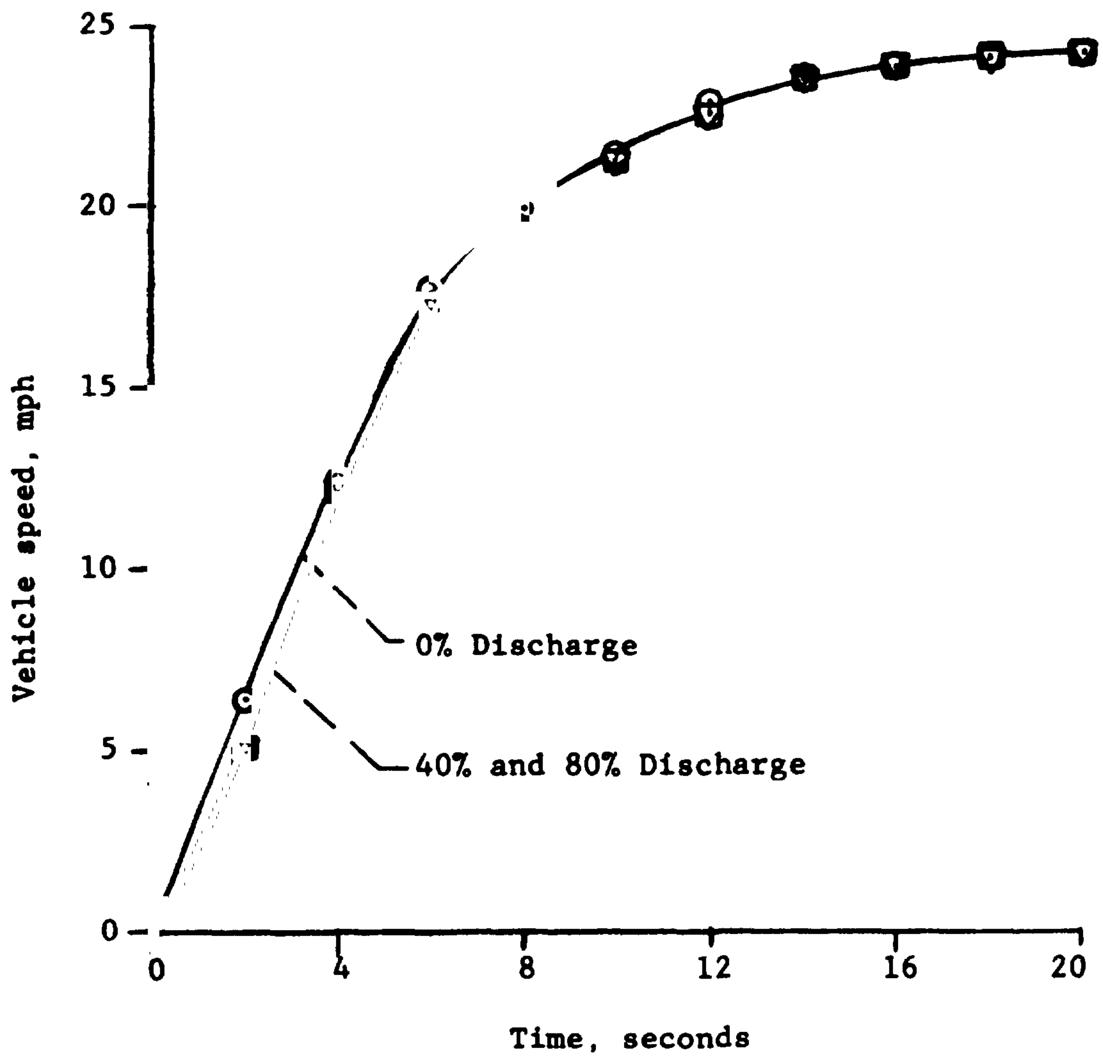

Figure 24. - Acceleration characteristics of Jet Industries Electra Van in second gear.

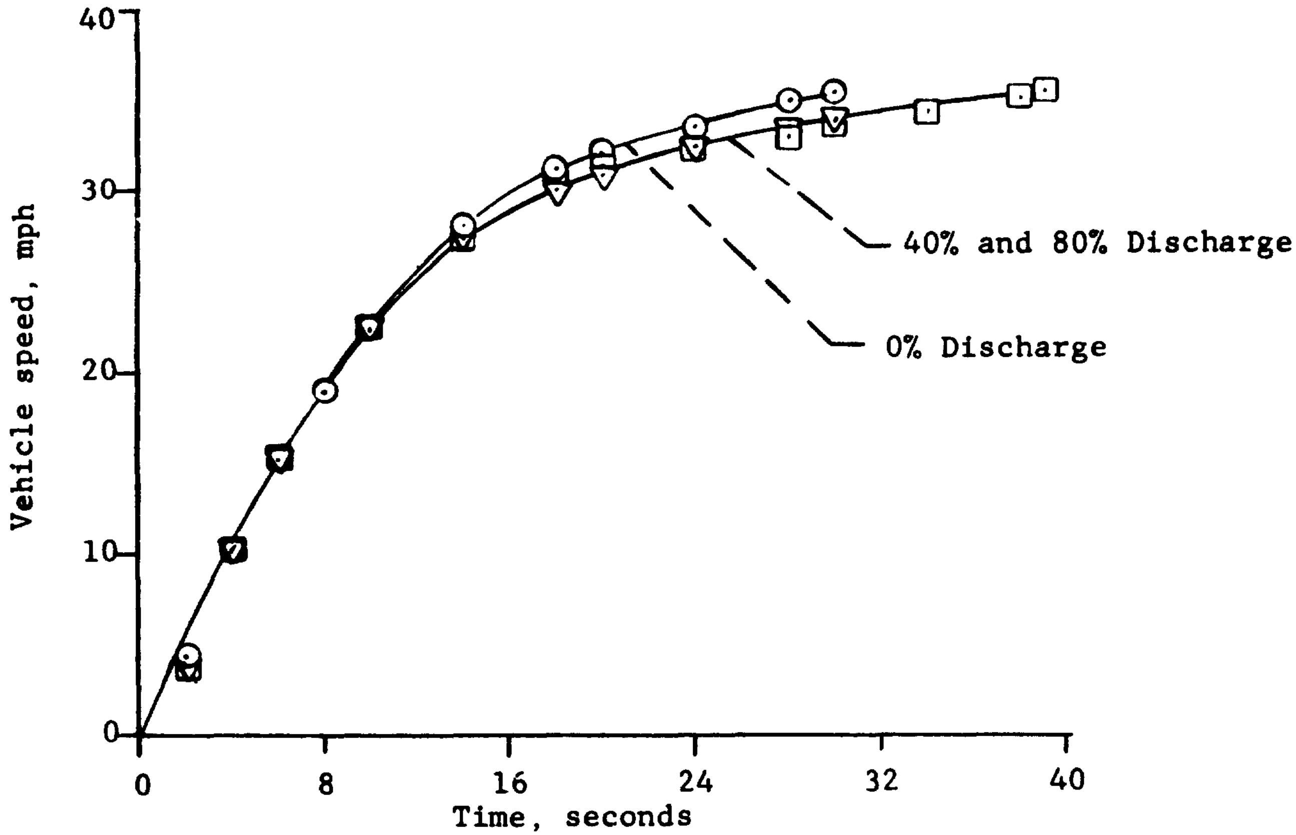

Figure 25. - Acceleration characteristics of Jet Industries Electra Van in third gear

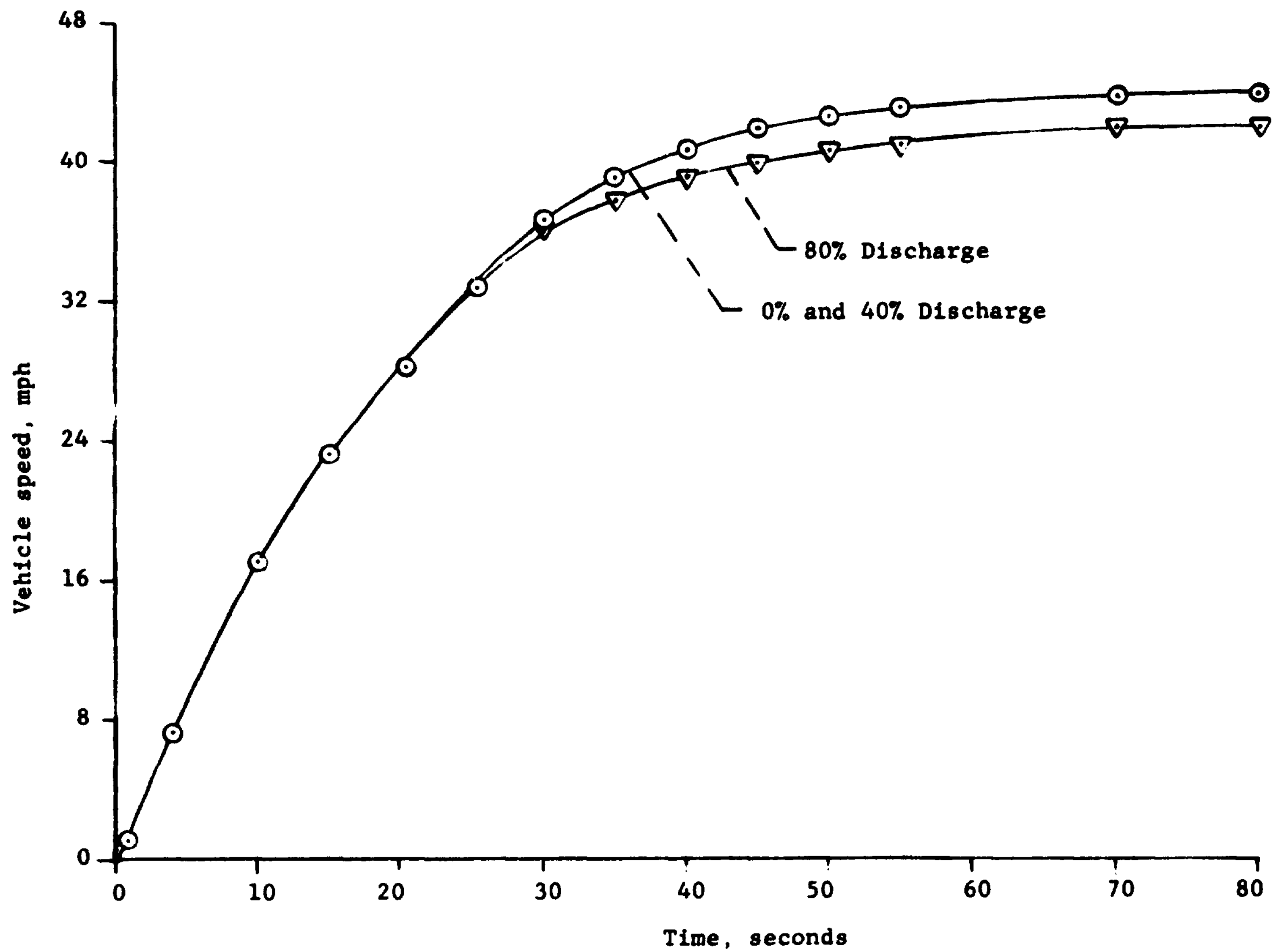

Figure 26. - Acceleration characteristics of Jet Industries Electra Van in fourth gear

TABLE 5. - JET INDUSTRIES ELECTRA-VAN ACCELERATION RESULTS

Gear	% Discharged	Time in seconds to speed indicated				Top speed
		10 mph	20 mph	30 mph	40 mph	
2nd	0	3.2	8			24.3
	40	3.4	8			24.3
	80	3.4	8			24.3
3rd	0	4.0	8.8	16.2		35.5
	40	4.0	8.8	17.0		34.0
	80	4.0	8.8	17.0		35.5
4th	0	5.5	12	22	37	44.0
	40	5.5	12	22	37	44.0
	80	5.5	12	22	45	42.0

Energy Consumption: The coast-down curve for the Electra-Van is presented in Figure 27. From this curve the round energy consumption, Figure 28, and the road power required, Figure 29, were derived.

A single measurement of the overall energy consumption using the Electra-Van's built-in charger was obtained for the 40-mph range-at-steady-speed test. This energy requirement was 2.56 miles/kilowatt-hour. The limited availability of the vehicle required the use of other battery charging equipment to meet the test schedule. Energy efficiencies calculated from test data using NASA-supplied charges is 2.94 miles/kilowatt-hour at 20 mph and 1.27 miles/kilowatt-hour for the SAE J227a, schedule A cycle. Data to compose the efficiencies of the charges is not available.

Special Tests

NASA's Lewis Research Center, with the help of two industrial contractors, has built experimental nickel-zinc batteries that feature an inorganic/organic separator adapted from space battery technology. This separator has been found to markedly improve charge-discharge cycle life.* The two special tests described in this section were aimed at measuring the relative range improvements which could be realized by replacing the EV-106 lead-acid battery in the test vehicles with the LeRC nickel-zinc battery.

The first vehicle tested with the nickel-zinc battery was the Otis P-500 Van which was immediately available from in-service use at LeRC. Figure 30 shows the complete 60 cell nickel-zinc battery set used in the P-500 Van. Note that the vehicle's battery compartment required two, 30-cell packs to make up a full set.

Later, an opportunity arose to compare both the experimental nickel-zinc battery with the EV-106 lead-acid battery in the Copper Development Association's experimental "Copper Electric Town Car." The detailed results of these two vehicle tests follow. It should be noted that the number of tests performed with these vehicles was limited and no attempt was made to cover all the test requirements set forth in the SAE J227a test procedure.

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*D. W. Sheibley, J. Electrochem. Soc., vol. 123, pg. 702, 1976, Abstracts No. 24 and 25.

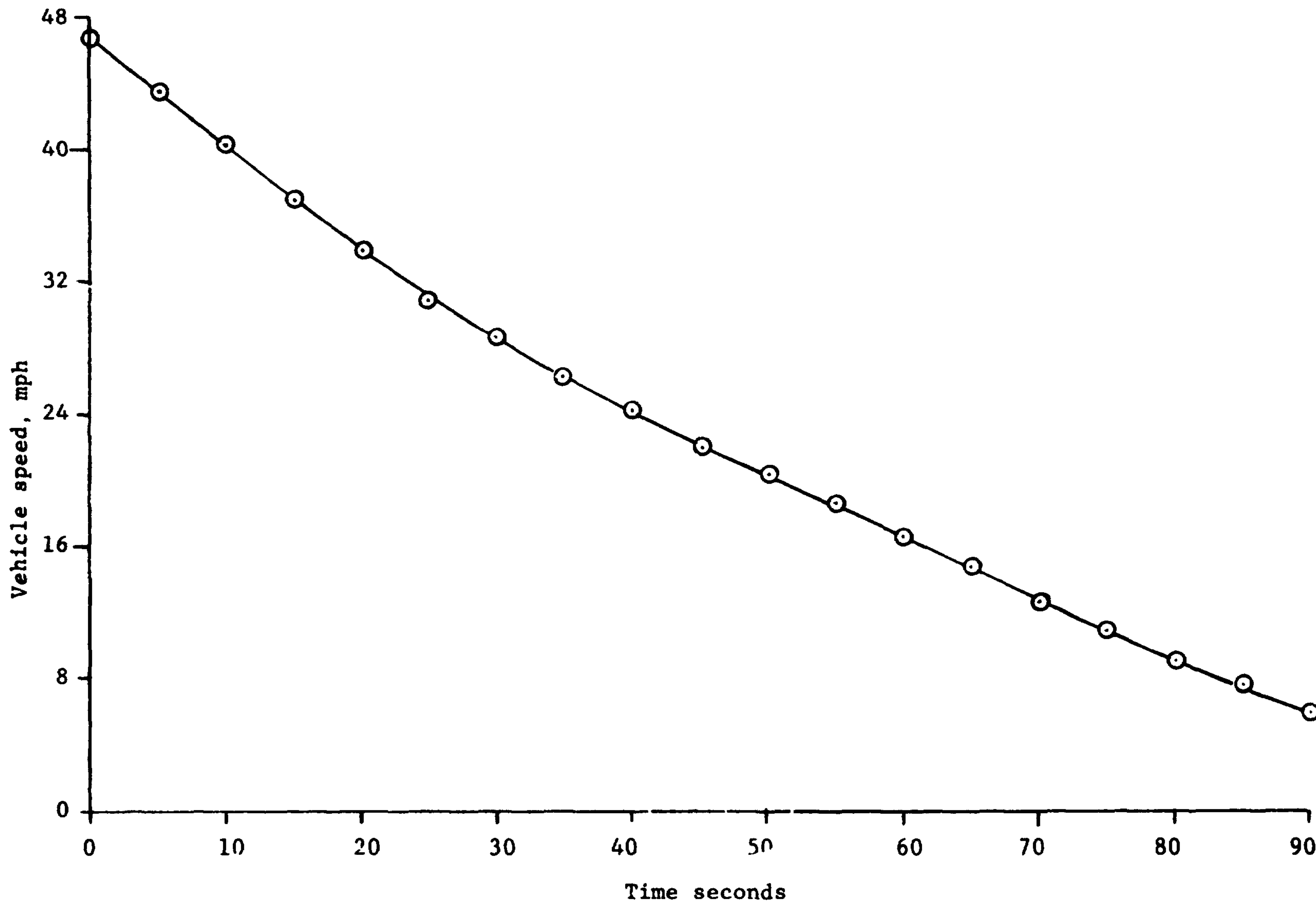

Figure 27. - Vehicle speed as a function of time during coasting for Jet Industries Electra Van

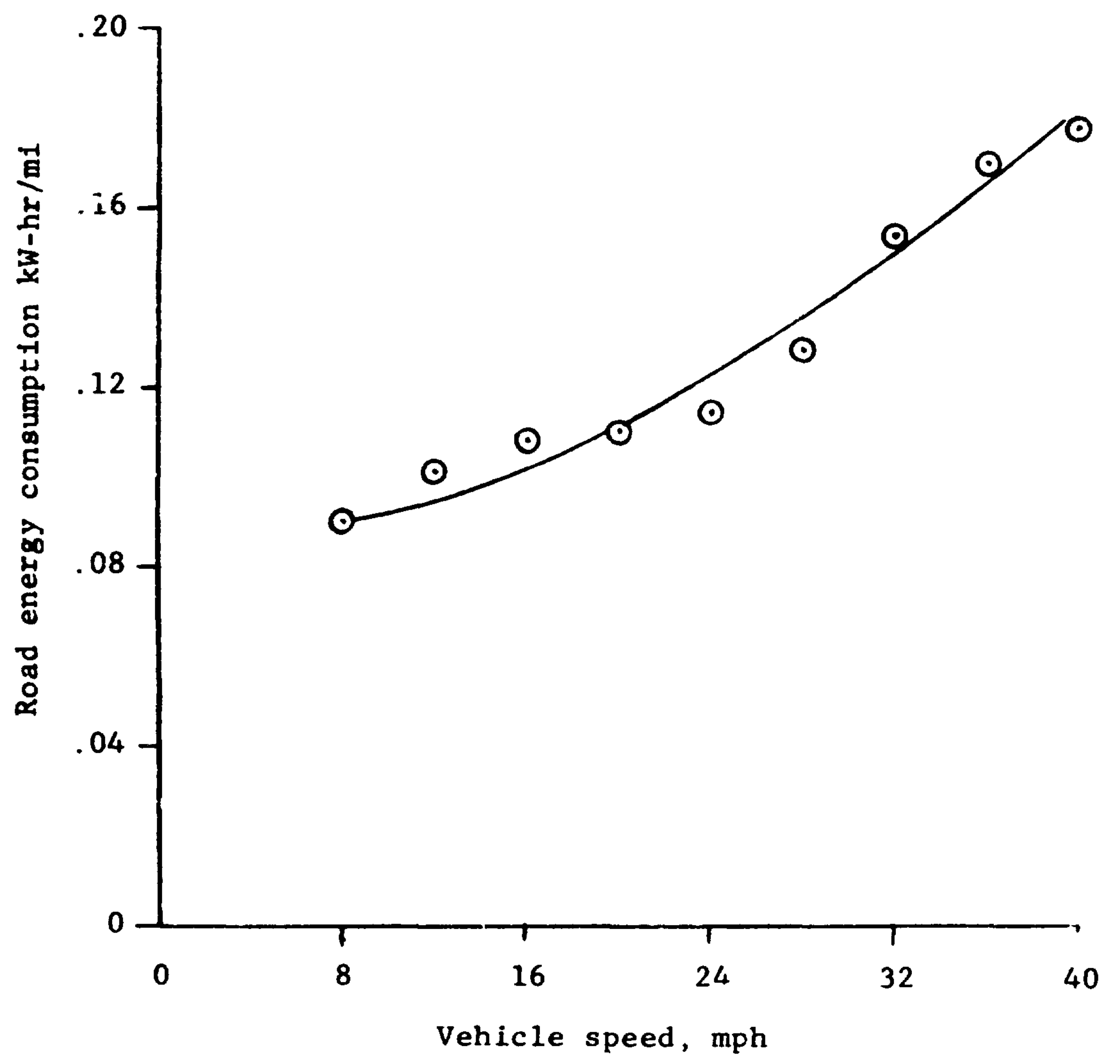

Figure 28. - Road energy consumption as a function of vehicle speed for Jet Industries Electra Van

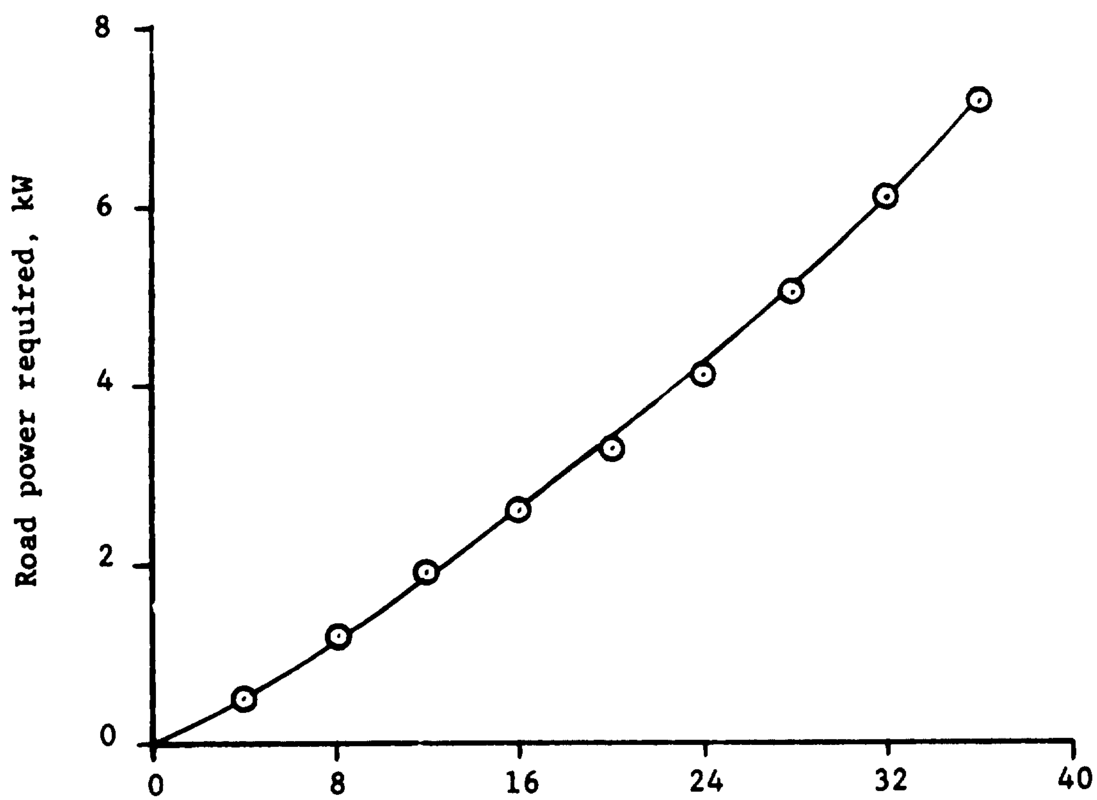

Figure 29. - Road power required as a function of vehicle speed for Jet Industries Electra Van

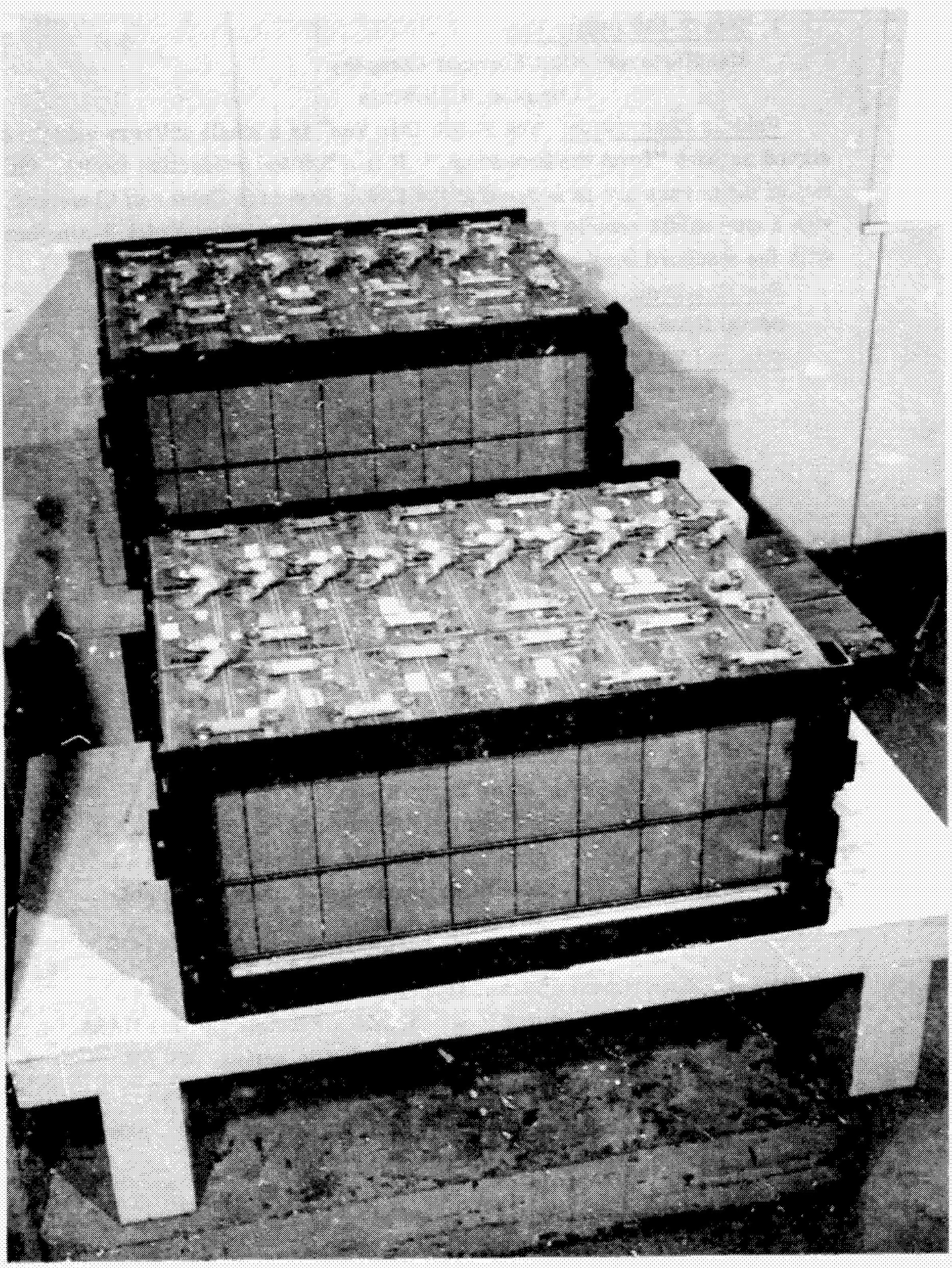

Figure 30. - The 60 cell, nickel-zinc battery set used for the Otis P-500 van tests.

1. Otis P-500 Utility Van

Manufacturer: Otis Elevator Company
Compton, California

Vehicle Description: The P-500 Otis Van* is a small delivery vehicle designed as such "from the ground up." It is a limited production model. Since two of these vans are in service at the Lewis Research Center in Cleveland, it was a convenient vehicle to use to compare the experimental nickel-zinc battery with the standard lead-acid units now available.

Specifications:

Serial Number - 2-75

Size and Weight

- Length . . . . 138.0 in.
- Width . . . . 62.0 in.
- Height . . . . 74.2 in.
- Cargo Volume (750 lb work load) . . . . 87 ft^3
- Road Clearance . . . . 7.2 in.
- Projected Frontal Area . . . . 30.0 ft^2
- Curb Weight . . . . 3620 lb.
- Test Weight . . . . 4445 lb.

Batteries (used for test)

- Main Traction:
    - Lead-acid:
        - Manufacturer - Exide Corp.
            - Type - golf cart, EV-106
            - Normal rating - 106 minutes at 75 amp (132.5 amp-hr), sixteen 6-volt units used in a 96-volt series string (8 units in each of two battery boxes)
            - Weight - 1040 pounds
    - Experimental nickel zinc:
        - Manufacturer - Yardney Electric Co. for NASA
            - Nominal rating - 60 cells in series, 300 AH
            - Nominal voltage - 96 volts at 75 amp load
            - Weight - 1110 pounds
- Accessory - 12-volt, lead-acid SLI type

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*No longer in production.

Traction Motor

- Type - Otis series dc, blower cooled
- Rating - 30 hp at 4000 rpm (max)

Controller

- Solid state (SCR), 96-volt, electronic pulse type (General Electric Co.)

Transmission

- None used, motor drives the rear axle differential through a conventional propeller shaft with universal joints at both ends

Drive Axle

- Conventional rear drive differential unit
- Ratio - 5.17:1

Wheels

- Tires - Uniroyal Rally 180, 175-SR-13, 6-ply radial
- Tire pressure - 32 psi
- Rear wheel standing radius - 11.1 in.
- Rear wheel rolling distance - 6.08 ft/rev
- Wheel base - 96.0 in.
- Wheel track

  Front - 51.0 in.

  Rear - 51.0 in.

Figure 31 shows an overall view of the P-500 van used in this test outfitted for its in-use service with the Lewis Research Center's fire department. Some of the van's drive train detail can be seen in Figure 32 photographed through the right side sliding door looking to the rear of the vehicle. The 12-volt accessory battery and the two groups of traction batteries can be seen under the raised portion of the load space floor. One of two traction battery groups containing eight 6-volt units each is inserted through hatches in both sides of the van using a special lifting device supplied with the van. Under the driver and passenger's seat in the front of the van can just be seen the top of the traction motor and its cooling air blower. The chopper controller components are located in this same compartment on either side of the traction motor.

Results: Road tests on the Otis van were performed at the Dana Test Track Facility during April 1976. The purpose of the tests was to compare vehicle performance with lead-acid batteries with the performance of an experimental nickel-zinc battery designed by NASA and built by a commercial battery company.

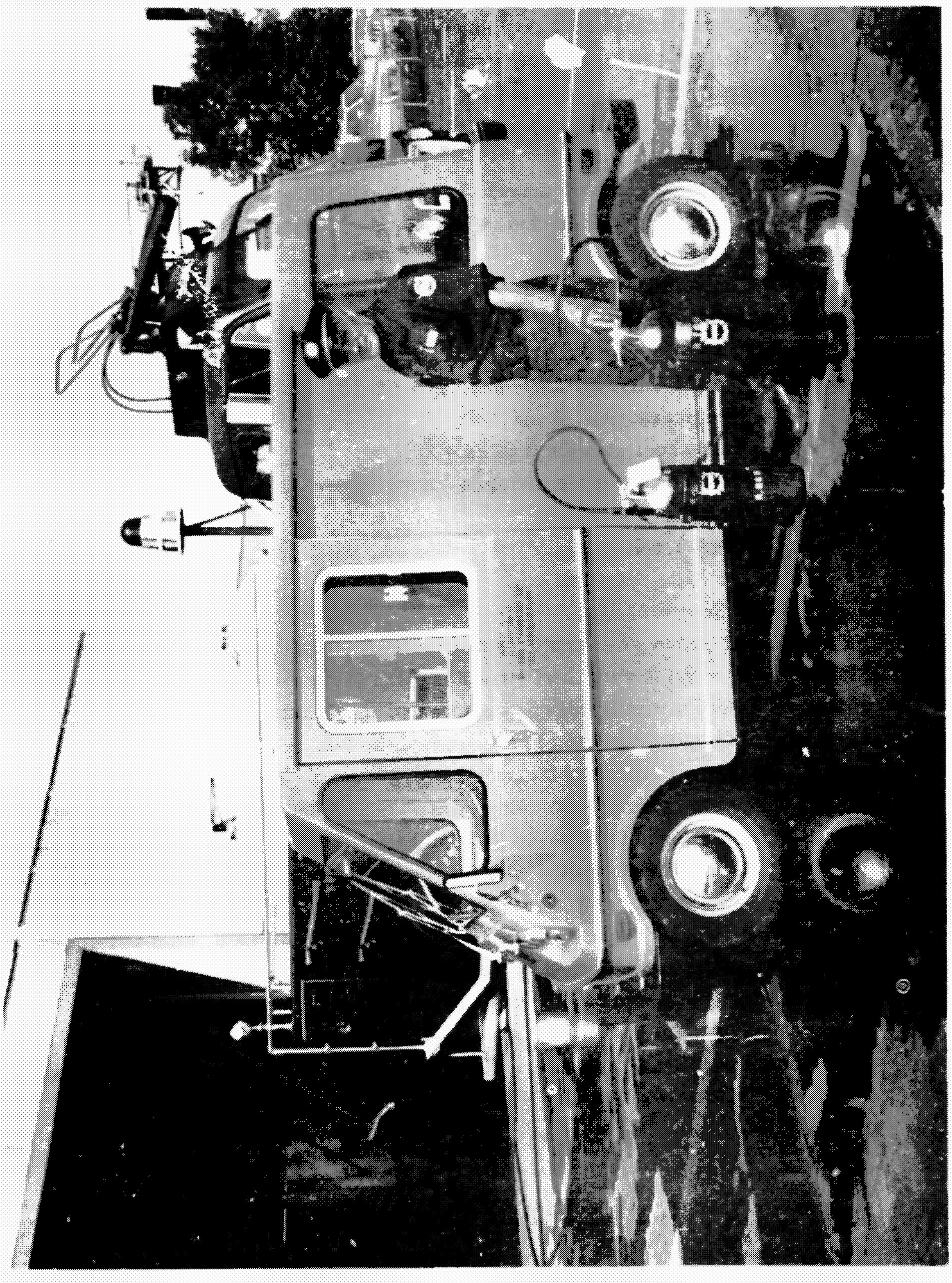

Figure 31. - Overall view of the Otis P-500 van in service with the Lewis Research Center Fire Department.

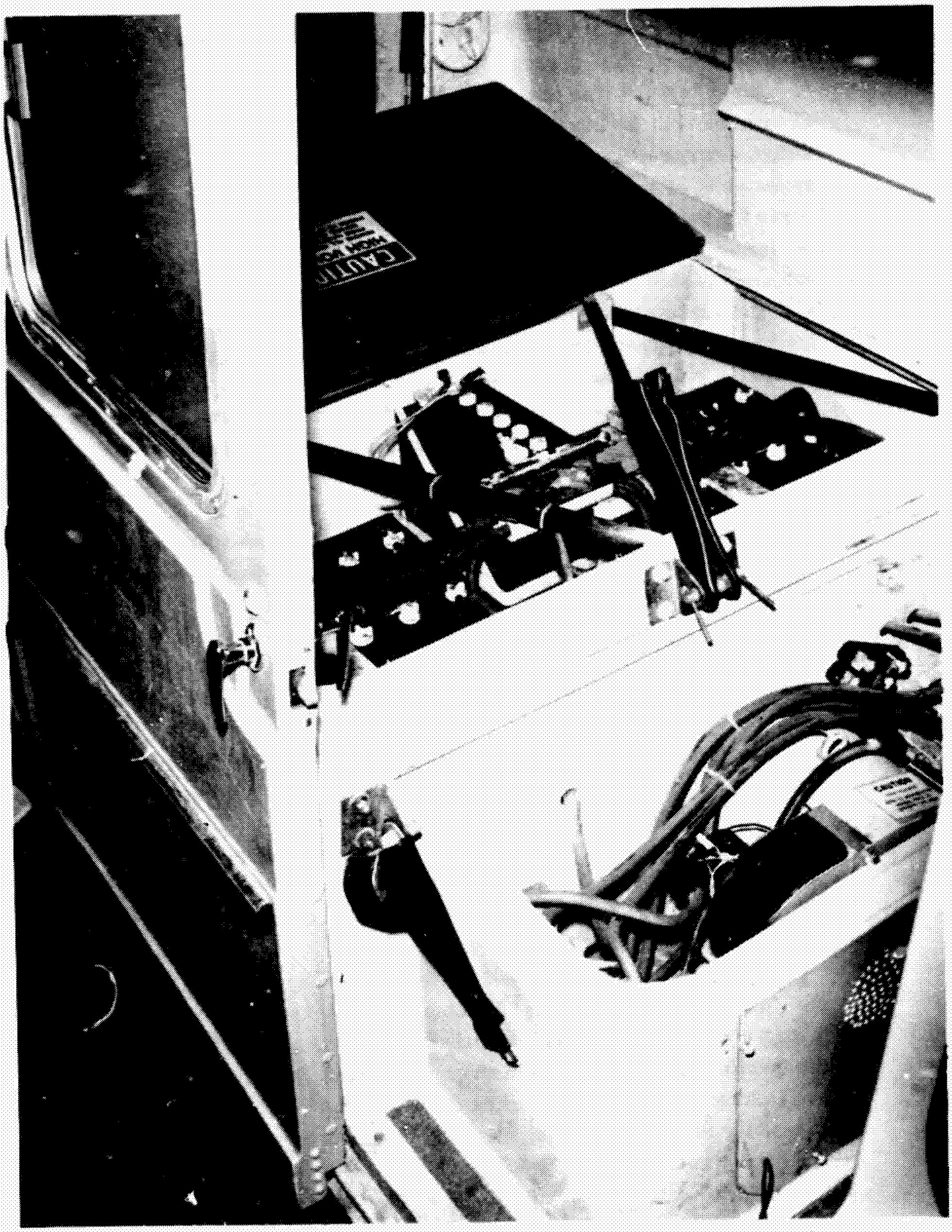

Figure 32. - View to the rear through right door of Otis P-500 van showing some drive train components.

Meteorology. - During the tests the wind velocity averaged 12 mph with gusts to 20 mph while the temperature averaged 43° F.

Range tests. - The constant speed range tests were performed at 20 mph ±1 mph for both the lead-acid and nickel-zinc battery systems. The vehicle test weight was normalized at 4445 for both tests. The tests were terminated for both batteries at 84 volts which was at the mid-point of the "knee" of the discharge curve for both batteries. At the constant speed of 20 mph the Otis van using the lead-acid batteries traveled 29.4 miles. With the nickel-zinc battery the vehicle was able to go 54.9 miles or a range increase of 87 percent.

The stop-and-start driving cycle tests were performed in accordance with the SAE J227a Test Procedure Schedule B in which the vehicle is accelerated to 20 mph within 19 seconds, followed by a cruise at 20 mph for 19 seconds, a coast for 4 seconds, braking to a stop in 5 seconds, and an idle for 25 seconds. Termination of the test was at the cycle in which the battery voltage dropped to 84 volts during the acceleration portion of the cycle.

A summary of the range test results is presented in Table 6.

The results of the test show that the Otis van with lead-acid batteries traveled 21.1 miles. With nickel-zinc batteries the vehicle traveled 42.4 miles for a range increase of 101 percent.

Acceleration tests. - The maximum acceleration tests were performed with 100 percent charged lead-acid batteries. As can be seen in Figure 33 the Otis van was able to accelerate to 30 mph in 12 to 13 seconds but took 40 seconds to reach a top speed of 39 mph.

From Figure 33 the acceleration capabilities versus speed were calculated and are presented in Figure 34. As can be seen the acceleration peaks at 4 to 5 mph/second at less than 5 mph.

Gradeability. - Using the acceleration data the gradeability of the Otis van was calculated and is shown in Figure 35. At a reasonable speed of 20 mph the vehicle can climb a 14-percent grade but at 35 mph the gradeability decreases to less than a 2-percent grade.

Coast-down tests. - Coast-down tests were run on the Otis van to determine the road load of the vehicle. The motor was not disconnected when the coast-down tests were conducted. As of the present time, no corrections have been made for the inertia of the motor since data on the inertial characteristics of the motor are lacking. In general, including the motor in the coast-down test would increase the deceleration rate, resulting in an increase in the calculated power and energy consumption. Results of the coast-down test is presented in Figure 36

TABLE 6. - OTIS P-500 VAN RANGE TEST RESULTS

Note: During these tests neither wind nor temperature conditions conform to the SAE J227a Test Procedure. The wind speed averaged 12 mph with gusts to 20 mph and the temperature averaged 43° F.

Test Battery	Range at Steady 20 mph, miles	Schedule "B" 20 mph Cycle range, miles	No. of cycles
Exide EV-106	29.4	21.1	99
LeRC Nickel-Zinc	54.9	42.4	190

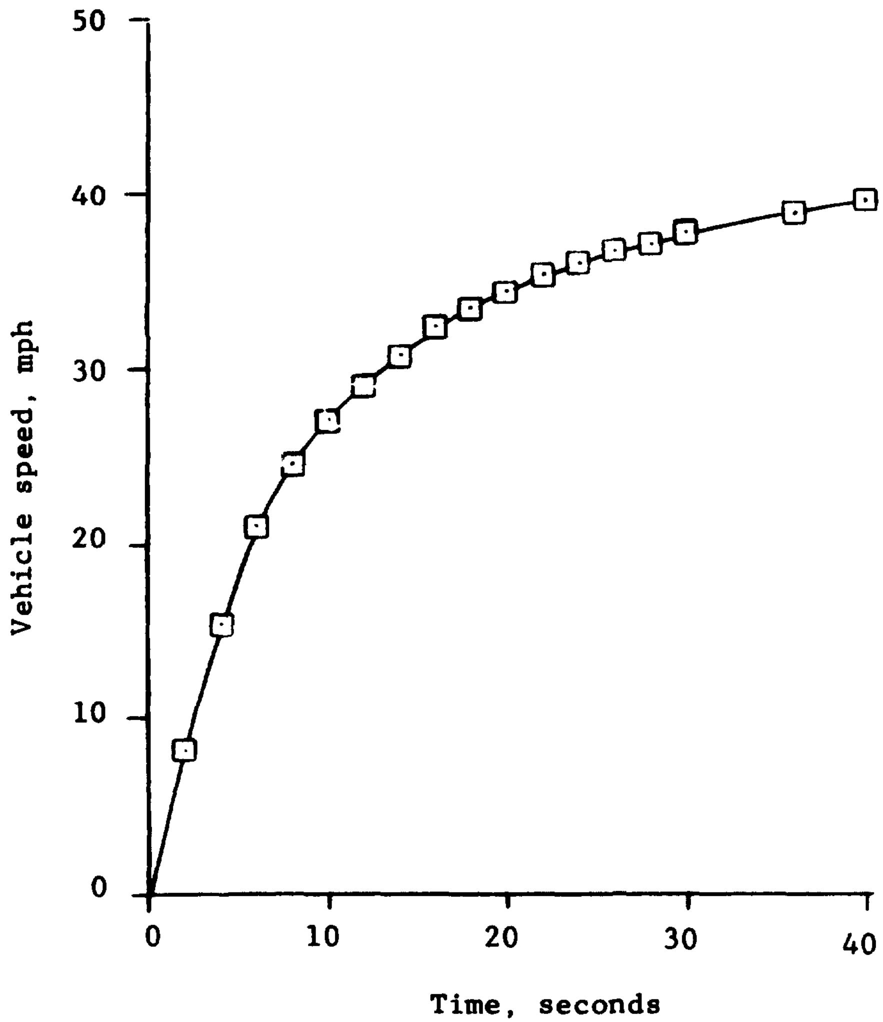

Figure 33. - Acceleration characteristics of Otis P-500 utility van

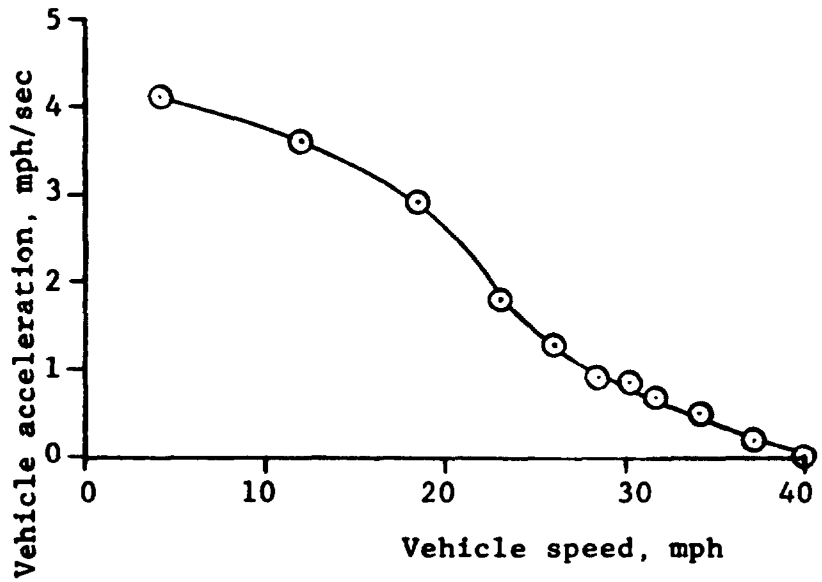

Figure 34. - Vehicle maximum acceleration as a function of vehicle speed for Otis P500 Utility Van

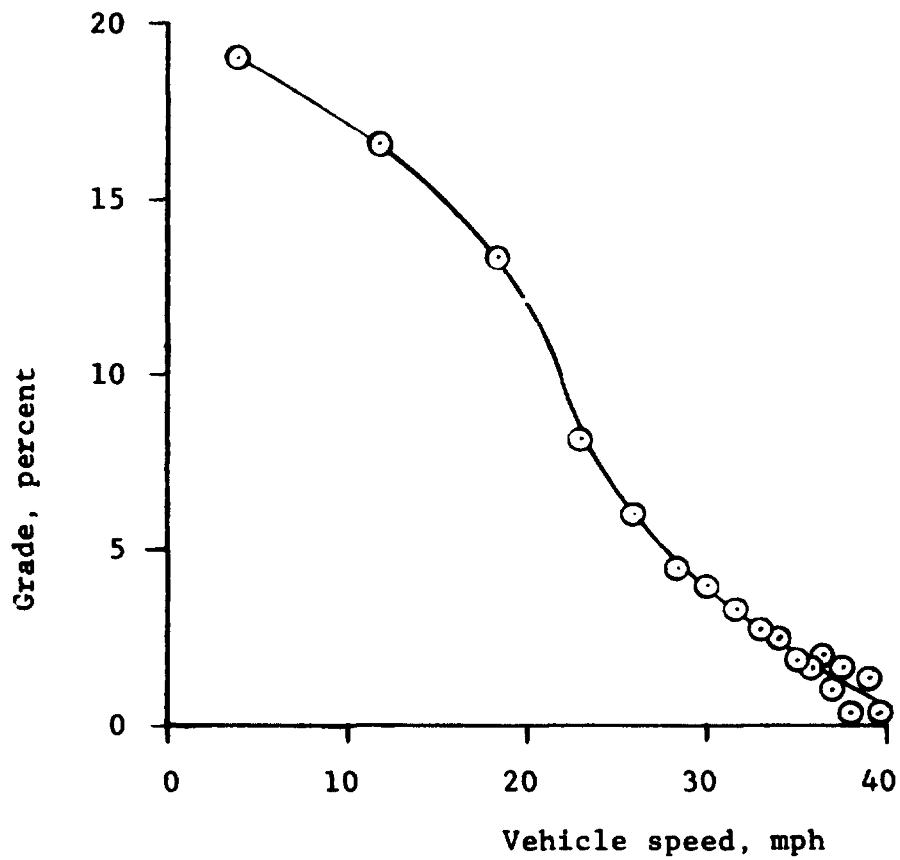

Figure 35. - Gradability of Otis P500 Utility Van

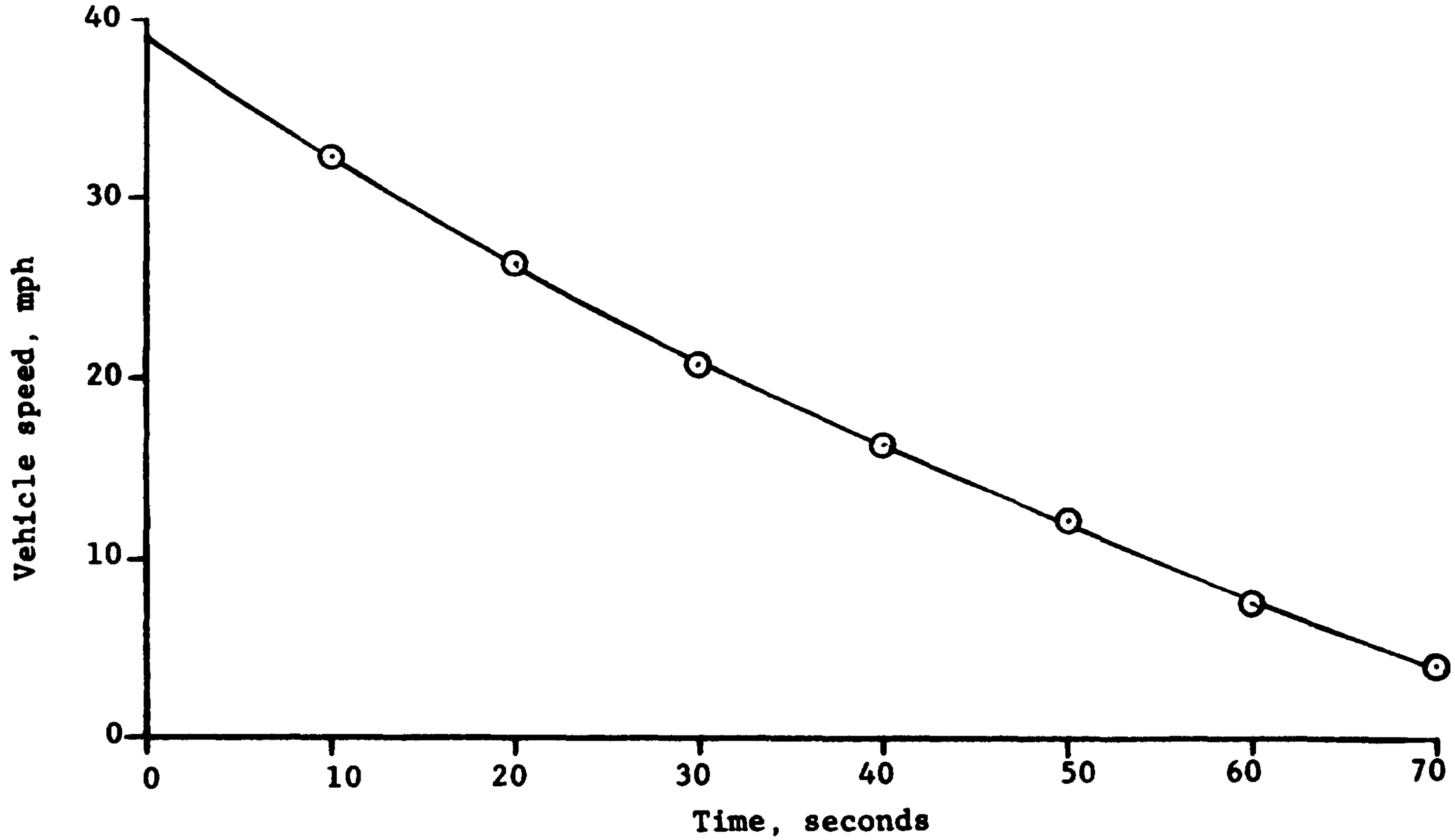

Figure 36. - Vehicle speed as a function of time during coasting for Otis P500 Utility Van

as speed versus time. Calculations of the road energy and power consumption as a function of speed are presented in Figures 37 and 38, respectively. As can be seen the vehicle requires 0.14 kilowatt-hour/mile of energy and 1.0 kilowatt of power at a speed of 5 mph while at 35 mph the energy requirement is 0.275 kilowatt-hour/mile and the power requirement is 10 kilowatts.

Battery Performance: Presented in Figure 39 is the power delivered by the Pb/Acid battery at various constant speeds. As can be seen, the power required at a speed of 20 mph is 8.15 kilowatts while at 35 mph the power required is 15.2 kilowatts.

During the constant speed range test using Pb/Acid and Ni-Zn batteries the voltage and average current were determined. Presented in Figure 40 is the battery voltage as a function of distance traveled at a speed of 20 mph. The voltage curve for the Ni-Zn batteries droops less with range than that for the Pb/Acid batteries.

2. CDA Town Car

Manufacturer: Triad Services Inc., Dearborn, Michigan

Vehicle Description: The CDA "Town Car" is an experimental, two-passenger car of the "hatchback" design. The compact car's electric drive train features front wheel drive, a low-loss spiral-bevel-gear differential, a separately excited field motor, and a central battery tunnel which doubles as the structural backbone of the car. The motor speed control system uses a combination of techniques - series resistors at very low speed, 2 battery voltage ranges (54 and 108 volts), and motor field control. The details of the motor and speed control system are reported in SAE Paper No. 750470.

Specifications:

Size and Weight

- Length . . . . 145.0 in.
- Width . . . . 60.0 in.
- Height . . . . 54.5 in.
- Road Clearance . . . . 8.0 in.
- Curb Weight . . . . 3100 lb.
- Test Weight (with Globe Union Batteries) . . . . . . 3460 lb.

Batteries

- Main Traction - specified as Globe Union type GC 2-21, eighteen 6-volt units required, total weight = 1062 pounds
- Field Control - three 12-volt Lucas units in a 36-volt series string, total estimated weight = 75 pounds

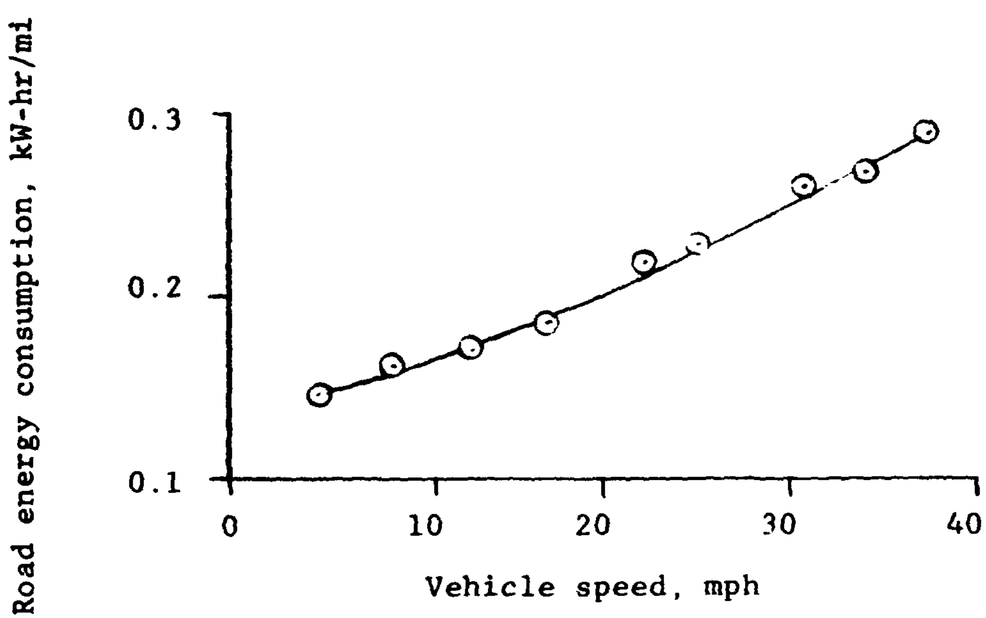

Figure 37. - Road energy consumption as a function of vehicle speed for Otis P500 Utility Van

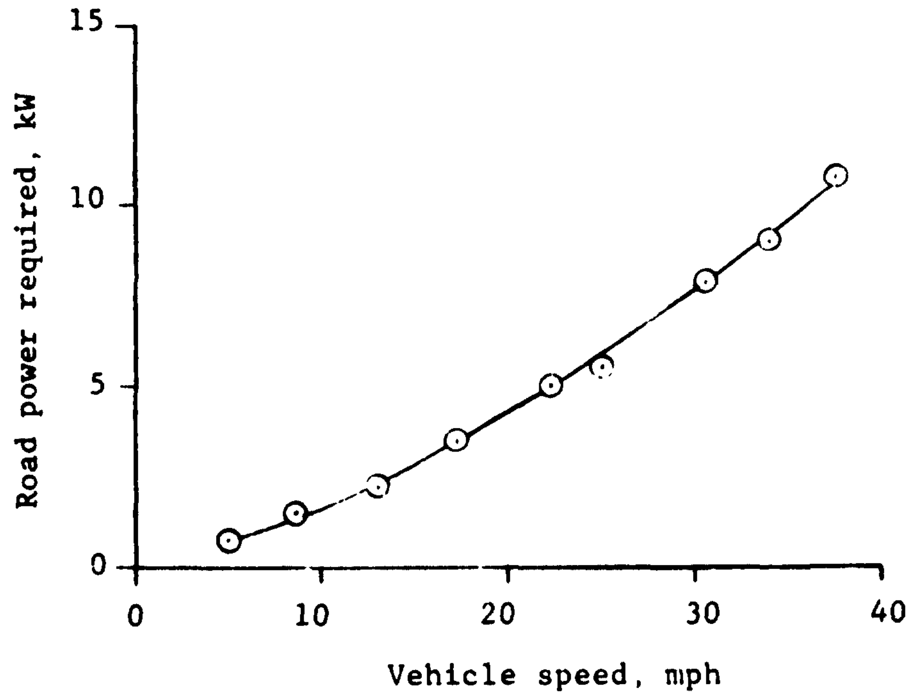

Figure 38. - Road power required as a function of vehicle speed for Otis P500 Utility Van

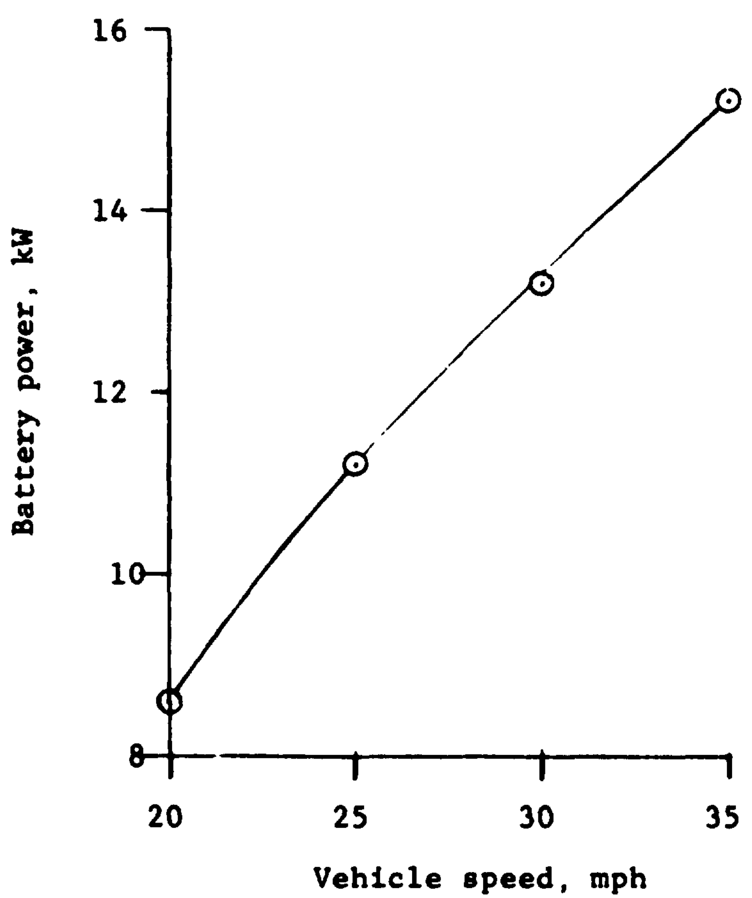

Figure 39. - Power delivered by the battery as a function of vehicle speed for Otis P500 Utility Van

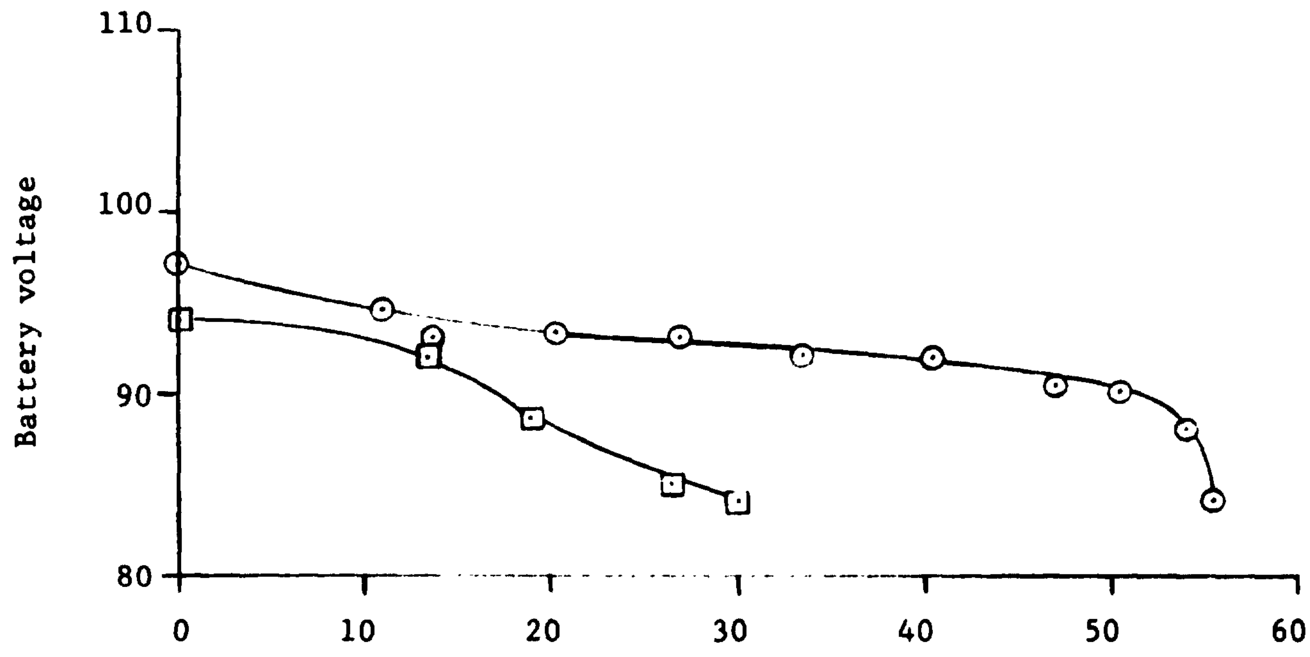

Figure 40. - Battery voltage as a function of distance traveled at 20 mph for Otis P500 Utility Van

- Accessory Battery - two 6-volt motorcycle type units in a 12-volt series connection, total estimated weight = 12 pounds
- Special lead-acid traction battery for test only, Exide type EV-106, eighteen 6-volt units, total weight = 1170 pounds
- Special experimental nickel-zinc battery supplied by Lewis Research Center for test only, 60 cells, nominal 96 volts at 75 amp load, 300 amp-hours; total weight=1110 pounds

Traction Motor

- Type - Triad Services separately excited, 4 pole with interpoles, 11.8 inches outside diameter, 17 inches long, 290 pounds weight
- Rating - 120 volts (no power or current rating available)

Controller

- Combination of series resistance (at very low speed), 2 voltage battery switching (54 and 108 volts), and motor field control. See SAE Paper No. 750470.
- Designed and built by Triad Services

Transmission

- Chain drive from motor to axle differential with a front wheel drive, overall drive ratio is fixed at 4.95:1

Drive Axle

- Features a spiral-bevel gear differential driving the front wheels through half-shafts with sliding, cross-type universal joints at the inner ends and Rzeppa constant-speed universal joints at the outer ends

Wheels

- Front drive wheels using Michelin steel radial 145 SR 13 ZX over-inflated to 48 psi, standing radius measured as 10.5 inches
- Rear wheels using "Firestone 500" BR 70-13 steel radial tires over-inflated to 48 psi
- Wheel base - 90 inches
- Wheel track

  Front - 51$\frac{3}{8}$ inches

  Rear - 52$\frac{1}{2}$ inches

Brakes

- Hydraulic drum brakes at all four wheels using copper alloy drums, self-energizing system

The curb weight of the car was obtained with the Globe Union batteries and no instrumentation as 3100 pounds. The actual test weights are given in Table 7. Figure 41 shows the CDA Town Car on the test track.

Results: The only tests planned in this special series were the range-at-steady-speed test at 40 mph and the schedule "D" 45 mph driving cycle using three different batteries (EV-106, GC-2-21, Nickel-zinc). The tests were all performed at the Dana test track during the week of August 2-6, 1976.

The test results are shown in Table 6. Notice that a 40-mph steady speed test run was not made with the Globe Union batteries due to failure of the drive motor before the test could be run.

At the constant speed of 40 mph the CDA car using EV-106 lead-acid batteries traveled 80.2 miles. With the nickel-zinc batteries the vehicle was able to go 146.3 miles or a range increase of 82 percent.

The motor problem referred to above was an over-heating condition evident on all of the schedule "D" 45-mph cycle runs on this vehicle. The traction motor does not have a cooling blower and during the 45-mph cycle tests with the two lead-acid test batteries, the front hood of the car was secured in a slightly open position to augment the motor cooling. This "fix" did not prevent the motor from overheating but the motor did not fail during these two runs. However, during the 45-mph cycle test with the nickel-zinc batteries, two factors combined to cause the motor to fail during the 50th cycle. The first factor was simply that the test was running longer than with the lead-acid batteries. The second factor was the nickel-zinc battery's lower voltage. The CDA vehicle is normally equipped with an experimental Globe-Union traction battery weighing 1062 pounds. The equivalent 108-volt EV-106 battery weighed 1170 pounds. Since the CDA controller is designed with two operating sections, each controlling one half of the battery, an even number of cells is required. A total of 62 nickel-zinc cells, having an open-circuit voltage of 99.2 volts could have been used and would weigh 1147 pounds. However, a decision was made to use 60 cells weighing 1110 pounds since this placed the nickel-zinc battery weight almost mid-way between the two lead-acid batteries. The result was a lower nickel-zinc battery voltage at any given drain. As an example, at a current draw of 255 amps the battery voltages were as follows:

Globe Union GC 2-21 - 96.1 volts
Exide EV-106 - 94.8 volts
LeRC Nickel-Zinc - 80.2 volts

TABLE 7. - CDA TOWN CAR TEST RESULTS

Meteorological data, average wind speed range and average air temperature appear in parentheses under the values for test range.

Test battery	Car test weight, lb	Range at steady 40 mph, mi	Schedule "D" 45-mph cycle range	
			Distance, mi	Number of cycles
Globe Union GC 2-21	3460	(No test)	41.3 (11 to 15 mph, 78° F)	38
Exide EV-106	3570	80.2 (5 to 6 mph, 84° F)	34.1 (15 to 20 mph, 82° F)	33
LeRC Nickel-zinc	3510	146.3 (7 to 9 mph, 80° F)	* (11 to 14 mph, 66° F)	*50

*Motor failure occurred during cycle number 50 of this test, range 49.7 miles. SAE Specification not followed due to attempts of driver to reduce motor overheating, actual cycle characteristics:
1. Average acceleration time = 41 seconds
2. Average time at 45 mph = 36.2 seconds
3. Average time under power = 77.2 seconds

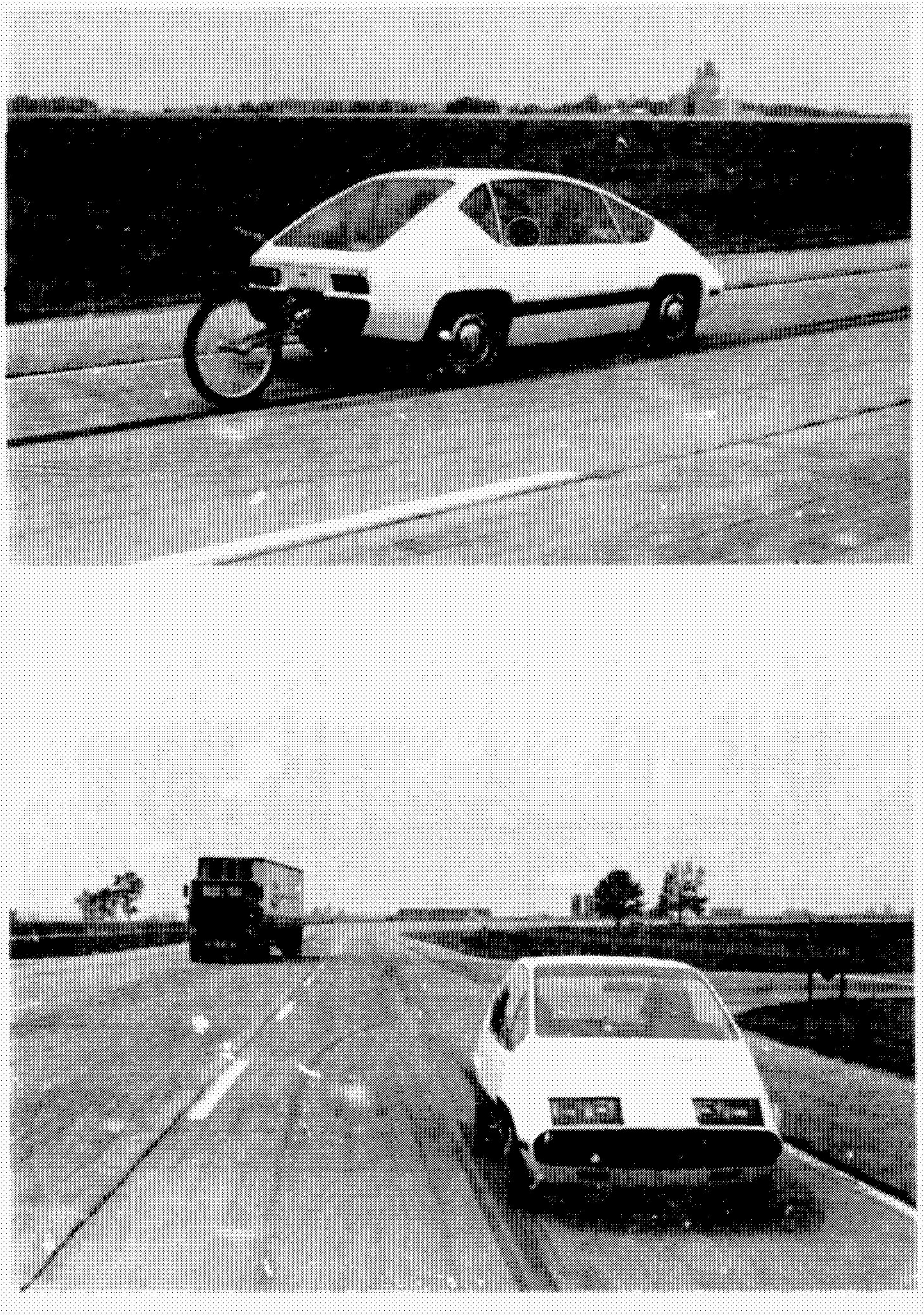

Figure 41. - The CDA Town Car on the Dana Corp. test track.

To produce the same acceleration power the vehicle motor was required to operate at a higher current with the nickel-zinc battery than with the lead-acid units and thus all electrical I^2R losses were greater during the nickel-zinc run. This increased the heating load by an estimated 20 percent over the schedule D driving cycle. Since the motor had already shown a tendency to overheat during both of the lead-acid tests, the Triad Services representative driving the car reduced the acceleration rates as indicated on Table 7. Despite this precaution, the motor failed on cycle number 50, having traveled a distance of 49.7 miles.

In summary, the CDA Copper Electric Town Car vehicle exhibits unusually low battery power draw during steady speed driving (62 amp at 105.8 volts at a steady 40 mph). Its general performance and acceleration using its design lead-acid batteries is very good, but some type of augmented motor cooling system is probably needed to prevent motor overheating on the most severe of the standard performance tests.

CONCLUSIONS AND RECOMMENDATIONS

The tests conducted to date have served to highlight several factors of importance to future vehicle testing activities.

Foremost among these is the question of whether the SAE J227a test procedure is an appropriate method for vehicle evaluation. While some aspects of the tests are subject to criticism, the J227a procedure is widely accepted in the United States as the "standard" method for testing electric vehicles and comparing the performance of one vehicle to another. The tests are designed to evaluate the performance of the entire vehicle, rather than the propulsion system or its components. This is consistent with the objectives of ERDA's Baseline Test and Evaluation project which is to establish the current state-of-the-art of electric vehicle technology. It would be possible to synthesize different driving cycle profiles against which to measure performance, but it would be difficult to establish at present that these cycles have any greater validity than those recommended by the SAE. Therefore, it is recommended that the SAE J227a test procedures continue to be used for the ERDA Baseline vehicle test project.

The procedure does contain certain problems which have been uncovered in the testing done to date. One is the large number of test runs which are required with long test periods. For example, if three range tests at different speeds and two driving cycle schedules are each run in triplicate as required, $7\frac{1}{2}$ track-days are required (even with an extra battery set to permit two tests per day). Adding acceleration and coast-down tests, at least two weeks of track time are required if no difficulties with weather or the vehicle are encountered. Shortening this time period would be desirable. In studying the procedures, it is readily seen that the constant speed range tests really evaluate the capacity of the propulsion battery. The energy requirement per mile should be constant and thus it might be possible to integrate the energy required over a relatively small number of driving cycles. In principle, an evaluation could be completed in a few days by shortening the test runs to periods only long enough to establish average energy consumption values. This approach may break down for vehicles with regenerative braking unless the energy returned to the battery can be accurately measured as well. From the consumer's point of view, however, the "bottom line" is the total distance he can travel in a particular vehicle. This means that at least one of each type of test still should be performed.

Based on the above considerations, it is recommended that the full J227a test procedure be used, and that data generated in early tests be analyzed to determine whether a valid method for shortening the required testing can be established.

Another aspect of the vehicle energy economy test procedure worth noting is that it contains an implicit assumption that the vehicle's charger is used to recharge the batteries between tests. Due to the number of tests to be performed it is necessary to provide extra batteries in order to run more than a single test each day. This also requires that several battery chargers be provided, which may have different efficiencies than the vehicle's charger. Frequently, this support equipment is of the workhorse variety, designed for durability rather than high efficiency. It is therefore recommended that the energy economy be computed on the basis of measured energy input to the battery, and that this value be corrected for the vehicles own charger efficiency.

Finally, good engineering practice requires that test results be compared at standard test conditions. No such requirement exists in the SAE recommended practice, which allows a wide ambient temperature range (5^{o} to 32^{o} C/40^{o} to 90^{o} F). Determining the correction to be applied will depend on the temperature effects on battery and other drive train components and will require extensive testing. It is recommended that future test results be normalized by applying as a minimum a capacity correction factor for the battery using data to be provided by the battery manufacturer.