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16. Abstract

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The Electric and Hybrid Vehicle Program was conducted under the guidance of the then Energy Research and Development Administration (ERDA), now part of the Department of Energy.

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ELECTRIC PASSENGER VEHICLE

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SUMMARY

The Elcar, an electric vehicle manufactured in Italy by Zagato, was tested at the Dynamic Science Test Track in Phoenix, Arizona, between April 13 and April 27, 1977. The tests are part of an Energy Research and Development Administration (ERDA) project to characterize the state-of-the-art of electric vehicles. This report presents the performance test results on the Elcar vehicle.

The Elcar Model 2000 is a two-passenger vehicle with a reinforced fiberglass body, powered by eight 12-volt batteries. The batteries are connected to the motor through an arrangement of contactors operated from a foot pedal in conjunction with a hand-operated switch. These contactors change the voltage applied to the 2-kilowatt motor. No regenerative braking was provided on this vehicle.

All tests were run at the gross vehicle weight of 653 kilograms (1440 lbm). The results of the tests are as follows:

Test speed or driving cycle	Type of test						
	Range		Road power, kW	Road energy		Energy consumption	
	km	mile		MJ/km	kWh/mile	MJ/km	kWh/mile
40 km/h (25 mph)	42.5	26.4	1.9	0.17	0.075	0.72	0.32
Schedule B	39.1	24.3	---	----	-----	.78	.35

The Elcar was able to accelerate from 0 to 32 kilometers per hour (0 to 20 mph) in 8 seconds.

INTRODUCTION

The vehicle tests and the data presented in this report are in support of Public Law 94-413 enacted by Congress on September 17, 1976. The law requires the Energy Research and Development Administration (ERDA) to develop data characterizing the state-of-the-art of electric and hybrid vehicles. The data so developed are to serve as a baseline (1) to compare improvements in electric and hybrid vehicle technologies, (2) to assist in establishing performance standards for electric and hybrid vehicles, and (3) to help guide future research and development activities.

The National Aeronautics and Space Administration (NASA) under the direction of the Electric and Hybrid Research, Development, and Demonstration Office of the Division of Transportation Energy Conservation of ERDA has conducted track tests of electric vehicles to measure their performance characteristics and vehicle component efficiencies. The tests were conducted according to ERDA Electric and Hybrid Vehicle Test and Evaluation Procedure, described in appendix E of reference 1. This procedure includes the Society of Automotive Engineers (SAE) J227a procedure (ref. 2). Seventeen electric vehicles have been tested under this phase of the program, 12 by NASA, 4 by MERADCOM, and 1 by the Canadian government.

The assistance and cooperation of the Elcar Corporation, the vehicle representative in the United States, is greatly appreciated. The Energy Research and Development Administration provided funding support and guidance during this project.

U.S. customary units were used in the collection and reduction of data. The units were converted to the International System of Units for presentation in this report. U.S. customary units are presented in parentheses. The parameters, symbols, units, and unit abbreviations used in this report are listed here for the convenience of the reader.

Parameter	Symbol	SI units		U.S. customary units	
		Unit	Abbreviation	Unit	Abbreviation
Acceleration	a	meter per second squared	m/s^2	mile per hour per second	mph/s
Area	---	square meter	m^2	square foot; square inch	ft^2; in^2
Energy	---	megajoule	MJ	kilowatt hour	kWh
Energy consumption	E	megajoule per kilometer	MJ/km	kilowatt hour per mile	kWh/mile
Energy economy	---	megajoule per kilometer	MJ/km	kilowatt hour per mile	kWh/mile
Force	P	newton	N	pound force	lbf
Integrated current	---	ampere hour	Ah	ampere hour	Ah
Length	---	meter	m	inch; foot; mile	in.; ft; ---
Mass; weight	W	kilogram	kg	pound mass	lbm
Power	P	kilowatt	kW	horsepower	hp
Pressure	---	kilopascal	kPa	pound per square inch	psi
Range	---	kilometer	km	mile	---
Specific energy	---	megajoule per kilogram	MJ/kg	watt hour per pound	Wh/lbm
Specific power	---	kilowatt per kilogram	kW/kg	kilowatt per pound	kW/lbm
Speed	V	kilometer per hour	km/h	mile per hour	mph
Volume	---	cubic meter	m^3	cubic inch; cubic foot	in^3; ft^3

OBJECTIVES

The characteristics of interest for the Zagato Elcar are vehicle speed, range at constant speed, range over stop-and-go driving schedules, maximum acceleration, gradeability, road energy consumption, road power, indicated energy consumption, and battery characteristics.

TEST VEHICLE DESCRIPTION

The Elcar Model 2000 is a two-passenger electric vehicle manufactured in Italy by Zagato. The vehicle is powered by eight 12-volt batteries that are located under the floor in a slideout tray. The batteries are connected to the motor through contactors operated from a foot pedal in conjunction with a hand-operated switch. The 2-kilowatt motor is directly connected to the rear axle. The vehicle is shown in figure 1 and described in detail in appendix A. A 120-volt off-board battery charger is used to charge the traction batteries. No regenerative braking was provided on this vehicle.

Operating Characteristics

A hand switch is used to select three voltage levels to the motor in steps of 12, 24, and 48 volts. After the first step (12 V) is selected, the foot pedal is depressed to the first position. This connects the batteries through the hand switch to the motor through a current-limiting resistor. Depression of the foot pedal to the second position energizes a contactor to bypass the resistor. To increase speed, the foot pedal should be released (no current flowing to the motor) and the hand switch stepped to the next position before again depressing the foot pedal. Maximum speed is attained with the hand switch in the third step and the foot pedal in the second position. Two additional steps are provided on the hand switch for reverse and for charging.

INSTRUMENTATION

The Zagato Elcar vehicle was instrumented to measure vehicle speed and range, ampere-hours from and to the traction battery, and the battery charger power. The instrumentation package was located entirely on board the vehicle.

A schematic diagram of the electric propulsion system with the instrumentation sensors is shown in figure 2. A Nucleus Corporation Model NC-7 precision speedometer (fifth wheel) was used to measure vehicle velocity and distance traveled. Auxiliary equipment used with the fifth wheel included a Model ERP-X1 electronic pulser for distance measurement, a Model NC-PTE pulse totalizer, a Model ESS/E expanded-scale speedometer, and a programmable digital attenuator. The fifth wheel was calibrated before each test by rotating the wheel on a constant-speed fifth-wheel calibrator drum mounted on the shaft of a synchronous alternating current (AC) motor. The accuracy of the distance and velocity readings were within 0.5 percent of reading. Distance and velocity were recorded on a strip-chart recorder on board the vehicle.

The integrated battery current was measured for the battery pack with a current shunt and an on-board current integrator and was recorded manually after each test. This value represents the ampere-hours delivered by one-half of the battery pack. The current integrator is a Curtis SHR-C3 current integrator. The integrator was calibrated periodically to within ±1 percent of reading. In addition, battery electrolyte temperatures and specific gravities were measured manually before and after the tests.

Power for the fifth wheel and current integrator was provided from a 12-volt starting, lighting, and ignition (SLI) instrumentation battery. A Tripp Lite 500-watt DC/AC inverter provided the AC power.

All instruments were calibrated periodically. The integrator and strip-chart recorder were calibrated with a Hewlett-Packard Model 6920 B meter calibrator, which has a 0.2-percent-of-reading accuracy and a usable range of between 0.01 and 1000 volts.

The current and voltage into the battery and the energy into the battery charger were measured while the battery was being recharged after each test. The current and voltage to the battery were recorded on a Honeywell 195 Electronik two-channel, strip-chart recorder. The energy delivered to the charger was measured with a General Electric Type 1-50A single-phase, residential, watt-hour meter.

TEST PROCEDURES

The tests described in this report were performed at the Dynamic Science Test Track, a two-lane, 3.22-kilometer (2-mile) asphalt track located in Phoenix, Arizona. A complete description of the track is given in appendix B. When the vehicle was delivered to the test track, the pretest checks described in appendix C were conducted. The first test was a formal shakedown to familiarize the driver with the operating characteristics of the vehicle, to check out all instrumentation systems, and to determine the vehicle's maximum speed (appendix C). All tests were run in accordance with ERDA Electric and Hybrid Vehicle Test And Evaluation Procedure ERDA-EHV-TEP, appendix E of reference 1, at the gross weight of the vehicle, 653 kilograms (1440 lbm). No braking tests or tractive force tests were performed on the Elcar. The procedure also includes tests for handling, but at ERDA's direction they were not conducted.

Range Tests at Constant Speed

The vehicle speed for the highest constant-speed range test was determined during checkout tests of the vehicle. It was specified as 95 percent of the minimum speed the vehicle could maintain on the test track when it was traveling at full power. This speed was 40 kilometers per hour (25 mph) for the Elcar.

Range tests at constant speeds were run at 40 kilometers per hour (25 mph). The speed was held constant within ± 1.6 kilometers per hour (1 mph), and the test was terminated when the vehicle could no longer maintain 95 percent of the test speed. The range tests were run at least twice.

Range Tests under Driving Schedules

The 32-kilometer-per-hour (20-mph), schedule B, stop-and-go driving cycle, shown in figure 3, was run with this vehicle. A complete description of cycle tests is given in appendix E of reference 1. A special instrument, called a cycle timer, was developed at the Lewis Research Center to assist in accurately running these tests. Details of the cycle timer are given in appendix C. The cycle tests were terminated when the test speed could not be attained in the time required under maximum acceleration.

Acceleration and Coast-Down Tests

The maximum acceleration of the vehicle was measured on a level road with the battery fully charged and 40 and 80 percent discharged. Four runs, two in each direction, were conducted at each of these three states of charge. Depth of discharge was determined from the number of ampere-hours removed from the batteries. Acceleration runs were made on the southern straight section of the track, and coast-downs on the northern straight section (appendix B, fig. B-1). Coast-down data were taken immediately after the acceleration test with fully charged batteries in order to start the coast-down run from maximum attainable vehicle speed.

TEST RESULTS

Range

The data collected from all the range tests are summarized in table I. Shown in the table are the test date, the type of test, the environmental conditions, the range test results, the ampere-hours into and out of the battery, and the energy into the charger. These data were used to determine vehicle range, battery efficiency, and energy consumption.

During most of the test period, the winds were variable and gusty. Even though the wind was less than 16 kilometers per hour (10 mph), on several occasions the wind was blowing in different directions and at different velocities at two positions on the track. There was no indication that this variation in wind velocity significantly affected the range or other test results as long as the measured winds were less than about 16 kilometers per hour.

The maximum speed of the vehicle was measured during the checkout tests. It is defined as the average speed that could be maintained on the track under full power. The measured maximum speed was 48 kilometers per hour (30 mph) for this vehicle. This differs from the maximum speed used in the range tests.

Two 40-kilometer-per-hour (25-mph) and two schedule B range tests were run. All the test results are shown in table I.

Maximum Acceleration

The maximum acceleration of the vehicle was determined with the batteries fully charged and 40 and 80 percent discharged. Vehicle speed as a function of time is shown in figure 4 and table II. The average acceleration $\bar{a}_n$ was calculated for the time period t_{n-1} to t_n, where the vehicle speed increased from V_{n-1} to V_n, from the equation

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

and the average speed of the vehicle $\bar{V}$ from the equation

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

Maximum acceleration as a function of speed is shown in figure 5 and table II.

Gradeability

The maximum specific grade, in percent, that a vehicle can climb at an average vehicle speed $\bar{V}$ was determined from maximum acceleration tests by using the equations

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

in SI units

or

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

in U.S. customary units

where $\bar{a}_n$ is average acceleration in meters per second squared (mph/sec). The maximum grades the Elcar can negotiate as a function of speed are shown in figure 6 and table II.

Road Energy Consumption

Road energy is a measure of the energy consumed per unit distance in overcoming the vehicle's aerodynamic and rolling resistance plus the energy consumed in the differential drive shaft and the rotating motor. It was obtained during coast-down tests, when the differential was being driven by the wheels, and thus may be different than the energy consumed when the differential is being driven by the motor. In the case of the Elcar, there is no transmission; the motor is connected directly to the differential by a chain drive.

Road energy consumption E_n was calculated from the following equations:

$$E_n = 2.78 \times 10^{-4} W \frac{V_{n-1} - V_n}{t_n - t_{n-1}}, \text{ MJ/km}$$

or

$$E_n = 9.07 \times 10^{-5} W \frac{V_{n-1} - V_n}{t_n - t_{n-1}}, \text{ kWh/mile}$$

where

W vehicle mass, kg (lbm)

V vehicle speed, km/h (mph)

t time, s

The results of the road energy calculations are shown in figure 7 and table III.

Road Power Requirements

The road power is analogous to the road energy. It is a measure of vehicle aerodynamic and rolling resistance plus the power losses in the differential, the drive shaft, and the motor. The road power P_n required to propel a vehicle at various speeds is also determined from the coast-down tests. The following equations are used:

$$P_n = 3.86 \times 10^{-5} W \frac{V_{n-1}^2 - V_n^2}{t_n - t_{n-1}}, \text{ kW}$$

or

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

The results of road power calculations are shown in figure 8 and table III.

Indicated Energy Consumption

The vehicle indicated energy comsumption is defined as the energy required to recharge the battery after a test divided by the vehicle range achieved during the test, where the energy is the input to the battery charger.

The energy input to the battery charger was measured with a residential kilowatt-hour meter following each range test. Some overcharge of the batteries was usually required in order to assure that all cells of the battery were fully charged and the pack was equalized. The reported energy usage may be higher than would be experienced with normal vehicle field operation. Indicated energy consumptions for these range tests are tabulated in table I.

BATTERY CHARACTERISTICS

Manufacturer's Data

The batteries supplied with the Elcar were Masco 12-volt modules. Because of their deteriorated condition, they were replaced at NASA with Powerstar heavy-duty batteries manufactured by Astron. These batteries are not intended for deep-discharge service since they are modified SLI batteries designed for use in recreational vehicles. They were used in order to expedite the testing of the vehicle since the Masco batteries were not available.

The Elcar as manufactured and as tested contained 12-volt Powerstar heavy-duty batteries. The characteristics of these batteries, as supplied by the battery manufacturer, are shown in table IV. The Powerstar heavy-duty battery has two primary ratings: reserve capacity and cranking power. The reserve capacity rating is 25 amperes for 150 minutes to a voltage of 1.75 volts per cell (VPC). The cranking power rating is 480 amperes for 30 seconds at 0° F to 1.2 VPC. The battery also has a 20-hour rating of 83 ampere-hours.

Battery Acceptance

Prior to the road tests, the batteries in the vehicle were tested to assure that the battery capacity met the manufacturer's specifications. A capacity check was performed on the batteries using a constant-current load bank. The batteries were discharged in two 48-volt parallel packs at a rate of 25 amperes per cell until the battery voltage dropped to 1.75 VPC. The capacity (in Ah) removed per cell as a function of voltage is shown in figure 9. The batteries were able to deliver 58.7 ampere-hours per cell at 25 amperes per cell, which is 94 percent of the manufacturer's rated capacity. Therefore, the batteries were deemed acceptable.

In lieu of the 5-minute terminal integrity test, all terminals and terminal connections were cleaned and inspected.

VEHICLE RELIABILITY

Only one test was terminated prior to completion, a 40-kilometer-per-hour (25-mph) range test. After 15 kilometers a thermal overload circuit breaker tripped. The driver was able to reset the breaker after 5 minutes; he then continued the test for an additional 2 kilometers at which time the overload reoccurred terminating the test. The ambient temperature during the test was 29° to 31° C (85° to 89° F). This is believed to be the cause of the failure since the test was successfully repeated twice at a lower ambient temperature (table I).

APPENDIX A

VEHICLE SUMMARY DATA SHEET

1.0 Vehicle manufacturer Zagato
Milan, Italy

2.0 Vehicle Elcar Model 2000

3.0 Price and availability

4.0 Vehicle weight and load

- 4.1 Curb weight, kg (lbm) 553 (1220)
- 4.2 Gross vehicle weight, kg (lbm) 653 (1440)
- 4.3 Cargo weight, kg (lbm)
- 4.4 Number of passengers 2 places
- 4.5 Payload, kg (lbm) 100 (220)

5.0 Vehicle size

- 5.1 Wheelbase, m (in.) 1.30 (51)
- 5.2 Length, m (in.) 1.96 (77)
- 5.3 Width, m (in.) 1.32 (52)
- 5.4 Height, m (in.)
- 5.5 Head room, m (in.)
- 5.6 Leg room, m (in.)
- 5.7 Frontal area, m^2 (ft^2) 1.95 (21)
- 5.8 Road clearance, m (in.)
- 5.9 Number of seats 2

6.0 Auxiliaries and options

- 6.1 Lights (number, type, and function) 2 head, 2 tail, 4 park, 4 side, 2 brake, low battery

6.2 Windshield wipers 2 on front windshield

6.3 Windshield washers 1 on front windshield

6.4 Defroster no

6.5 Heater no

6.6 Radio no

6.7 Fuel gage light

6.8 Amperemeter no

6.9 Tachometer no

6.10 Speedometer yes, in km/h

6.11 Odometer yes, in km/h

6.12 Right- or left-hand drive left

6.13 Transmission no

6.14 Regenerative braking no

6.15 Mirrors rearview

6.16 Power steering no

6.17 Power brakes no

6.18 Other

7.0 Batteries

7.1 Propulsion batteries

7.1.1 Type and manufacturer lead-acid, heavy-duty Powerstar RV-827; Astron Manufacturing Co.

7.1.2 Number of modules 1 tray of 8 batteries

7.1.3 Number of cells 48

7.1.4 Operating voltage, V 12, 24, and 48 (switchable)

7.1.5 Capacity, Ah 83 (20-h rate)

7.1.6 Size of each battery, m (in.) height, 0.23 (9.0); width, 0.30 (11.75); length, 0.17 (6.75)

7.1.7 Weight, kg (lbm) 187 (412)

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

7.2 Auxiliary battery

7.2.1 Type and manufacturer none

7.2.2 Number of cells

7.2.3 Operating voltage, V __________

7.2.4 Capacity, Ah __________

7.2.5 Size, m (in.) __________

7.2.6 Weight, kg (lbm) __________

8.0 Controller

8.1 Type and manufacturer contactors and hand switch

8.2 Voltage rating, V __________

8.3 Current rating, A __________

8.4 Size, m (in.) __________

8.5 Weight, kg (lbm) __________

9.0 Propulsion motor

9.1 Type and manufacturer DC series; Scaglia

9.2 Insulation class __________

9.3 Voltage rating, V 24

9.4 Current rating, A __________

9.5 Horsepower (rated), kW (hp) 2 (2.6)

9.6 Size, m (in.) diameter, 0.18 (7.0); 0.29 (11.5)

9.7 Weight, kg (lbm) __________

9.8 Speed (rated), rpm 2100 (max. unknown)

10.0 Battery charger

10.1 Type and manufacturer full wage 8613; Lester Equipment Manufacturing Co., Inc.

10.2 On- or off-board type off board

10.3 Input voltage required, V 120 AC

10.4 Peak current demand, A 15

10.5 Recharge time, h 10

10.6 Size, m (in.) height, 0.28 (11); width, 0.23 (9); length, 0.30 (12)

10.7 Weight, kg (lbm) 13.6 (30)

10.8 Automatic turnoff feature yes, timer

11.0 Body

11.1 Manufacturer and type ______

11.2 Materials fiberglass

11.3 Number of doors and type 2 side

11.4 Number of windows and type 1 front, 1 rear, 2 side; glass

11.5 Number of seats and type 1 bench (divided)

11.6 Cargo space volume, m^3 (ft^3) ______

11.7 Cargo space dimensions, m (ft) 0.41×1.14×1.12 (16×45×44)

12.0 Chassis

12.1 Frame

12.1.1 Type and manufacturer welded construction

12.1.2 Materials steel

12.1.3 Modifications none

12.2 Springs and shocks

12.2.1 Type and manufacturer rear, coil; front, coil

12.2.2 Modifications ______

12.3 Axles

12.3.1 Manufacturer ______

12.3.2 Front ______

12.3.3 Rear ______

12.4 Transmission

12.4.1 Type and manufacturer ______

12.4.2 Gear ratios ____________________

____

12.4.3 Driveline ratio ____________________

12.5 Steering

12.5.1 Type and manufacturer rack and pinion

____

12.5.2 Turning ratio ____________________

12.5.3 Turning diameter, m (ft) ____________________

12.6 Brakes

12.6.1 Front hydraulic

12.6.2 Rear hydraulic

12.6.3 Parking mechanical, on rear wheels

12.6.4 Regenerative no

12.7 Tires

12.7.1 Manufacturer and type Michelin radial

____

12.7.2 Size 145SR10ZX

12.7.3 Pressure, kPa (psi):

Front 193 (32)

Rear 193 (32)

12.7.4 Rolling radius, m (in.) ____________________

12.7.5 Wheel weight, kg (lbm):

Without drum ____________________

With drum ____________________

12.7.6 Wheel track, m (in.):

Front ____________________

Rear ____________________

13.0 Performance

13.1 Manufacturer-specified maximum speed (wide-open throttle), km/h (mph)
48 (30)

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

13.3 Tested at cruise speed, km/h (mph) 40.2 (25)

____

APPENDIX B

DESCRIPTION OF VEHICLE TEST TRACK

The test track used to conduct the tests described in this report is located in Phoenix, Arizona. The track is owned and operated by Dynamic Science, a subsidiary of Talley Industries.

The test track is a paved, continuous two-lane, 3.2-kilometer- (2-mile-) long oval with an adjacent 40 000-square-meter (10-acre) skid pad. The inner lane of the track is not banked and was used for all cycle tests and all constant-speed tests of 56 kilometers per hour (35 mph) or under. The outer lane has zero lateral acceleration at 80 kilometers per hour (50 mph) and was used for tests over 56 kilometers per hour (35 mph). An elevation survey of the track is shown in figure B-1. Average grade is 0.66 percent on the northern straight section and 0.76 percent on he southern straight section. The surface of the track and skid pad is asphaltic concrete with a dry locked-wheel skid number of 82 and a wet locked-wheel skid number of 71.

Wet and dry braking-in-turn tests were conducted on the skid pad. Wet recovery tests were conducted on the test track after driving through the wet-brake water trough located near the northern straight section of the tracks. Both 20- and 30-percent grades are available for parking brake tests.

APPENDIX C

VEHICLE PREPARATION AND TEST PROCEDURE

Vehicle Preparation

When a vehicle was received at the test track, a number of checks were made to assure that it was ready for performance tests. These checks were recorded on a vehicle preparation check sheet, such as the one shown in figure C-1. The vehicle was examined for physical damage when it was removed from the transport truck and before it was accepted from the shipper. Before the vehicle was operated, a complete visual check was made of the entire vehicle including wiring, batteries, motor, and controller. The vehicle was weighed and compared with the manufacturer's specified curb weight. The gross vehicle weight (GVW) was determined from the vehicle sticker GVW. If the manufacturer did not recommend a GVW, it was determined by adding 68 kilograms (150 lbm) per passenger plus any payload weight to the vehicle curb weight.

The wheel alignment was checked, compared, and corrected to the manufacturer's recommended alignment values. The battery was charged and specific gravities taken to determine if the batteries were equalized. If not, an equalizing charge was applied to the batteries. The integrity of the internal interconnections and the battery terminals was checked by drawing either 300 amperes or the vehicle manufacturer's maximum allowed current load from the battery through a load bank for 5 minutes. If the temperature of the battery terminals or interconnections rose more than 60 degrees Celsius above ambient, the test was terminated and the terminal was cleaned or the battery replaced. The batteries were then recharged and a battery capacity check was made. The battery was discharged in accordance with the battery manufacturer's recommendations. To pass this test, the capacity must be within 20 percent of the manufacturer's published capacity at the published rate.

The vehicle manufacturer was contacted for his recommendations concerning the maximum speed of the vehicle, tire pressures, and procedures for driving the vehicle. The vehicle was photographed head-on with a 270-millimeter telephoto lens from a distance of about 30.5 meters (100 ft) in order to determine the frontal area.

Test Procedure

Each day, before a test, a test checklist was used. Two samples of these checklists are shown in figure C-2.

The first item under driver instructions on the test checklist is to complete the pretest checklist (fig. C-3).

Data taken before, during, and after each test were entered on the vehicle data sheet (fig. C-4). These data include

(1) Average specific gravity of the battery

(2) Tire pressures

(3) Fifth-wheel tire pressure

(4) Test weight of the vehicle

(5) Weather information

(6) Battery temperatures

(7) Time the test was started

(8) Time the test was stopped

(9) Ampere-hours out of the battery

(10) Fifth-wheel distance count

(11) Odometer readings before and after the tests

The battery charge data taken during the charge cycle were also recorded on this data sheet. These data include the average specific gravity of the battery after the test, the kilowatt-hours and ampere-hours put into the battery during the charge, and the total time of the charge.

To prepare for a test, the specific gravities were first measured for each cell and recorded. The tire pressures were measured and the vehicle was weighed. The weight was brought up to the GVW by adding sandbags. The instrumentation was connected, and power from the instrumentation battery was applied. All instruments were turned on and warmed up. The vehicle was towed to the starting point on the track. If the data were being telemetered, precalibrations were applied to both the magnetic tape and the oscillograph. The fifth-wheel distance counter and ampere-hour integrator counter were reset to zero, and thermocouple reference junctions were turned on. The test was started and was carried out in accordance with the test checklist. When the test was terminated, the vehicle was brought to a stop and the post-test checks were made in accordance with the post-test checklist (fig. C-5). The driver recorded on the vehicle data sheet the time, the odometer reading, the ampere hour integrator reading, and the fifth-wheel distance reading. The post-calibration steps were then applied to the magnetic tape and the oscillograph. At the end of the test, weather data were recorded on the vehicle data sheet. All instrumentation power was turned off, the instrumentation battery was disconnected, and the fifth wheel was raised. The vehicle was then towed back to the garage, the post-test specific gravities were measured for all cells and the vehicle was placed on charge.

After the test, the engineer conducting the test completed a test summary sheet (fig. C-6). This data sheet provides a brief summary of the pertinent information received from the test. Another data sheet, the engineer's data sheet (fig. C-7), was also filled out. This data sheet summarizes the engineer's evaluation of the test and provides a record of problems, malfunctions, changes to instrumentation, etc., that occurred during the test.

Weather data. - Wind velocity and direction and ambient temperature were measured at the beginning and at the end of each test and every hour during the test. The wind anemometer was located about 1.8 meters (6 ft) from the ground near the southern straight section of the track. The ambient temperature readings were taken at the instrumentation trailer near the west curve of the track. During most of the test period the winds were variable and gusty.

Determination of maximum speed. - The maximum speed of the vehicle was determined in the following manner. The vehicle was fully charged and loaded to gross vehicle weight. After one warmup lap, the vehicle was driven at wide-open throttle for three laps around the track. The minimum speed for each lap was recorded and the average was calculated. This average was called the vehicle maximum speed. This speed takes into account track variability and maximum vehicle loading. This quantity was then reduced by 5 percent and called the recommended maximum cruise test speed.

Cycle timer. - The cycle timer (fig. C-8) was designed to assist the vehicle driver in accurately driving SAE schedules B, C, and D. The required test profile is permanently stored on a programmable read-only memory (PROM), which is the heart of the instrument. This profile is continuously reproduced on one needle of a dual-movement analog meter shown in the figure. The second needle is connected to the output of the fifth wheel and the driver "matches needles" to accurately drive the required schedule.

One second before each speed transition (e.g., acceleration to cruise or cruise to coast), an audio signal sounds to forewarn the driver of a change. A longer duration audio signal sounds after the idle period to emphasize the start of a new cycle. The total number of test cycles driven is stored in a counter and can be displayed at any time with a pushbutton (to conserve power).

REFERENCES

1. Sargent, Noel B.; Maslowski, Edward A.; Soltis, Richard F.; and Schuh, Richard M.: Baseline Tests of The C.H. Waterman DAF Electric Passenger Vehicle. NASA TM-73757, 1977.

2. Society of Automotive Engineers, Inc.: Electric Vehicle Test Procedure - SAE J227a. Feb. 1976.

TABLE I. - SUMMARY OF TEST RESULTS FOR ZAGATO ELCAR[a]

(a) SI units

Test date	Test condition (constant speed, km/h; or driving schedule)	Wind velocity, km/h	Temperature, °C	Range, km	Cycle life, number of cycles	Current out of batteries, Ah	Current into batteries, Ah	Energy into charger, MJ	Indicated energy consumption, MJ/km
4/14/77	40.2	8	21	42.0	---	51.5	72.0	----	----
4/16/77	B	11	24	40.5	113	57.1	70.5	29.2	0.72
4/19/77	40.2	16	27	42.8	---	50.4	66.2	30.2	.72
4/25/77	B	Calm	29	37.7	110	56.9	72.3	32.4	.85

(b) U.S. customary units

Test date	Test condition (constant speed, mph; or driving schedule)	Wind velocity, mph	Temperature, °F	Range, miles	Cycle life, number of cycles	Current out of batteries, Ah	Current into batteries, Ah	Energy into charger, kWh	Indicated energy consumption, kWh/mile
4/14/77	25	5	70	26.1	---	51.5	72.0	----	----
4/16/77	B	7	75	25.2	113	57.1	70.5	8.1	0.32
4/19/77	25	10	80	26.6	---	50.4	66.2	8.4	.32
4/25/77	B	Calm	84	23.4	110	56.9	72.3	9.0	.38

[a]Problems encountered during 40.2-km/h (25-mph) test on 4/13/77: Thermal overload circuit breaker tripped after 15 km. It was reset 5 minutes later but tripped again after 2 km (test terminated at this point). Ambient temperature during test, 29° to 31° C (85° to 89° F).

TABLE II. - ACCELERATION AND GRADEABILITY FOR ZAGATO ELCAR

(a) At full battery charge

Vehicle speed		Time to reach designated vehicle speed, s	Vehicle acceleration		Gradeability, percent
km/h	mph		m/s^2	mph/s	
0	0	0	0	0	0
2.0	1.2	.3	1.73	3.87	18.0
4.0	2.5	.6	1.88	4.21	19.7
6.0	3.7	.9	1.82	4.06	19.0
8.0	5.0	1.3	1.57	3.51	16.3
10.0	6.2	1.7	1.18	2.64	12.2
12.0	7.5	2.2	1.07	2.39	11.0
14.0	8.7	2.7	1.17	2.62	12.1
16.0	9.9	3.2	1.10	2.46	11.3
18.0	11.2	3.7	1.02	2.28	10.5
20.0	12.4	4.3	.97	2.18	10.0
22.0	13.7	4.9	.99	2.22	10.2
24.0	14.9	5.4	.93	2.07	9.5
26.0	16.2	6.1	.94	2.11	9.7
28.0	17.4	6.6	1.08	2.31	10.7
30.0	18.7	7.2	.89	1.99	9.2
32.0	19.9	7.9	.63	1.42	6.5
34.0	21.1	9.0	.54	1.21	5.5
36.0	22.4	10.0	.52	1.17	5.4
38.0	23.6	11.2	.42	.94	4.3
40.0	24.9	12.6	.32	.71	3.2
42.0	26.1	15.0	.21	.46	2.1
44.0	27.4	18.1	.13	.29	1.3

(b) At 40-percent battery discharge

0	0	0	0	0	0
2.0	1.2	.3	1.81	4.05	18.9
4.0	2.5	.6	1.88	4.20	19.6
6.0	3.7	.9	1.69	3.78	17.6
8.0	5.0	1.3	1.46	3.26	15.1
10.0	6.2	1.7	1.34	2.99	13.8
12.0	7.5	2.1	1.29	2.89	13.4
14.0	8.7	2.5	1.26	2.81	13.0
16.0	9.9	3.0	1.15	2.58	11.9
18.0	11.2	3.5	1.11	2.49	11.5
20.0	12.4	4.0	1.19	2.66	12.3
22.0	13.7	4.5	1.22	2.72	12.6
24.0	14.9	4.9	1.31	2.94	13.6
26.0	16.2	5.3	1.23	2.75	12.7
28.0	17.4	5.8	.93	2.08	9.6
30.0	18.7	6.5	.78	1.75	8.0
32.0	19.9	7.3	.72	1.61	7.4
34.0	21.1	8.1	.61	1.35	6.2
36.0	22.4	9.1	.45	1.00	4.6
38.0	23.6	10.6	.34	.75	3.4
40.0	24.9	12.5	.26	.58	2.7
42.0	26.1	15.1	.18	.39	1.8

(c) At 80-percent battery discharge

0	0	0	0	0	0
2.0	1.2	.4	1.58	3.52	16.4
4.0	2.5	.7	1.65	3.69	17.2
6.0	3.7	1.0	1.58	3.36	15.6
8.0	5.0	1.5	1.31	2.92	13.5
10.0	6.2	1.9	1.28	2.86	13.2
12.0	7.5	2.3	1.28	2.85	13.2
14.0	8.7	2.8	1.16	2.60	12.0
16.0	9.9	3.3	1.13	2.52	11.6
18.0	11.2	3.8	1.14	2.54	11.7
20.0	12.4	4.3	1.18	2.65	12.2
22.0	13.7	4.7	1.19	2.66	12.3
24.0	14.9	5.2	1.06	2.38	11.0
26.0	16.2	5.8	.93	2.07	9.5
28.0	17.4	6.4	.83	1.85	8.6
30.0	18.7	7.1	.75	1.68	7.7
32.0	19.9	7.9	.61	1.36	6.3
34.0	21.1	8.9	.48	1.08	5.0
36.0	22.4	10.3	.38	.85	3.9
38.0	23.6	11.9	.28	.63	2.9

TABLE III. - ROAD ENERGY AND ROAD POWER FOR ZAGATO ELCAR

[Coast-down data.]

Vehicle speed		Test time, s	Road power		Road energy	
km/h	mph		kW	hp	MJ/km	kWh/mile
50.0	31.1	0	0	0	0	0
48.0	29.8	1.1	3.44	4.61	.26	.12
46.0	28.6	3.0	2.39	3.19	.19	.08
44.0	27.4	5.0	2.30	3.09	.19	
42.0	26.1	6.9	2.19	2.94	.19	
40.0	24.9	8.9	1.87	2.51	.17	
38.0	23.6	11.2	1.69	2.26	.16	.0[illegible]
36.0	22.4	13.4	1.66	2.23	.17	.07
34.0	21.1	15.6	1.63	2.18	.17	.08
32.0	19.9	17.6	1.44	1.94	.16	.07
30.0	18.6	20.1	1.27	1.70	.15	.07
28.0	17.4	22.4	1.24	1.66	.16	.07
26.0	16.2	24.7	1.02	1.37	.14	.06
24.0	14.9	27.6	.82	1.10	.12	.06
22.0	13.7	30.6	.78	1.04	.13	.06
20.0	12.4	33.3	.67	.90	.12	.05
18.0	11.2	36.6	.54	.72	.11	
16.0	9.9	40.1	.49	.65	.11	
14.0	8.7	43.3	.41	.55	.11	
12.0	7.5	47.0	.32	.42	.09	.04
10.0	6.2	50.9	.24	.32	.09	
8.0	5.0	55.4	.18	.25	.08	
6.0	3.7	59.7	.14	.19	.09	
4.0	2.5	63.9	.10	.13	.09	
2.0	1.2	67.9	.04	.05	.07	.03

TABLE IV. - CHARACTERISTICS OF POWERSTAR BATTERIES

Length, m (in.)	0.17 (6.75)
Width, m (in.)	0.30 (11.75)
Height (top of terminals), m (in.)	0.23 (9)
Weight, kg (lbm)	0.114 (51.5)
Fully charged specific gravity	1.265
Number of plates per battery	78

Figure 1. - Zagato Elcar Model 2000.

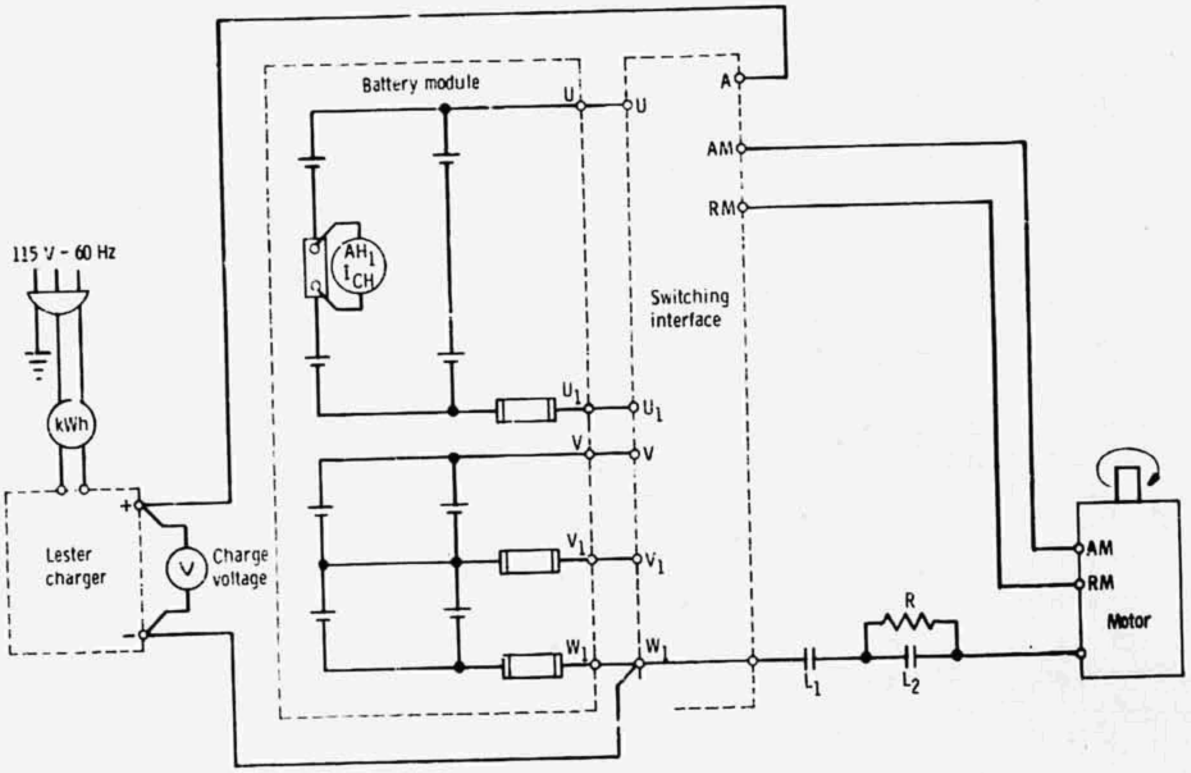
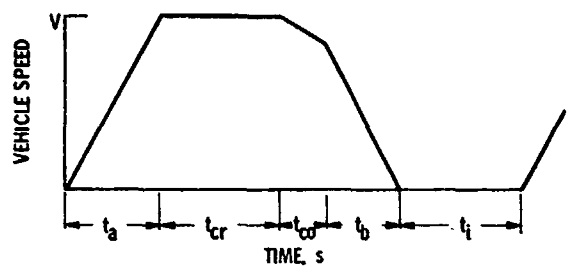


Figure 2. - Vehicle instrumentation for Zagato Elcar.



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

Figure 3. - SAE J227a driving cycle schedules.

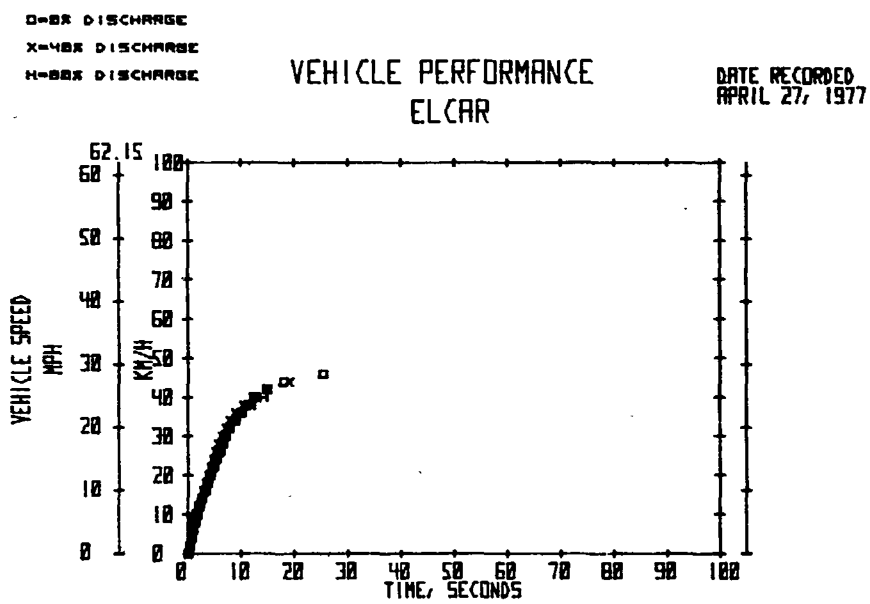


Figure 4. - Vehicle acceleration.

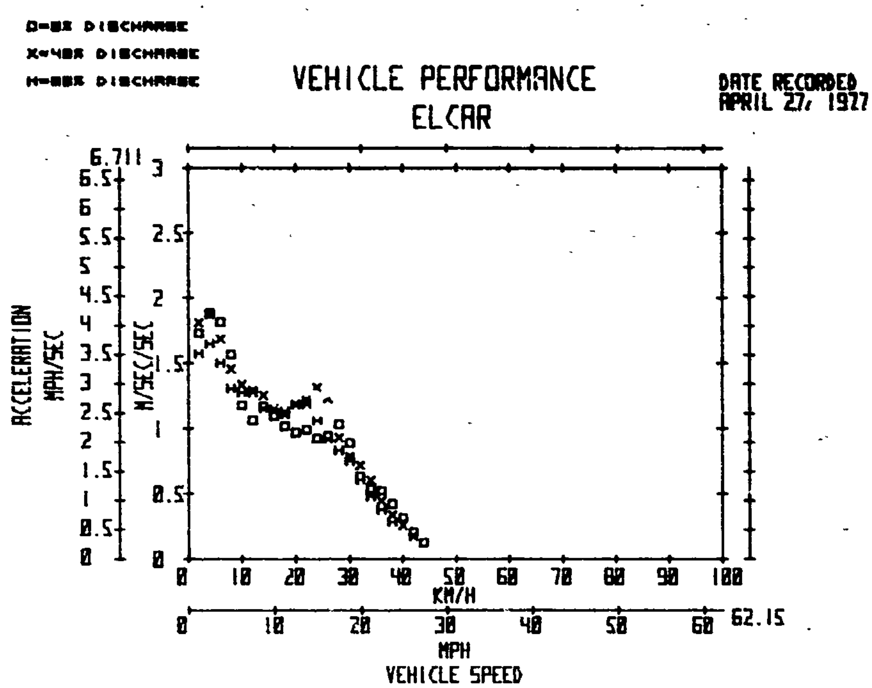


Figure 5. - Acceleration as a function of speed.

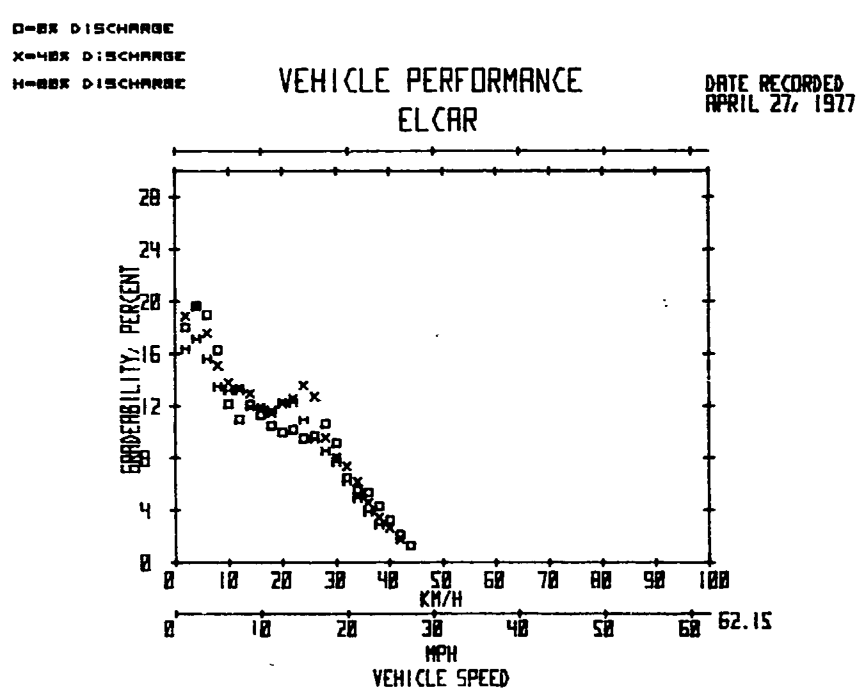


Figure 6. - Gradeability as a function of speed.

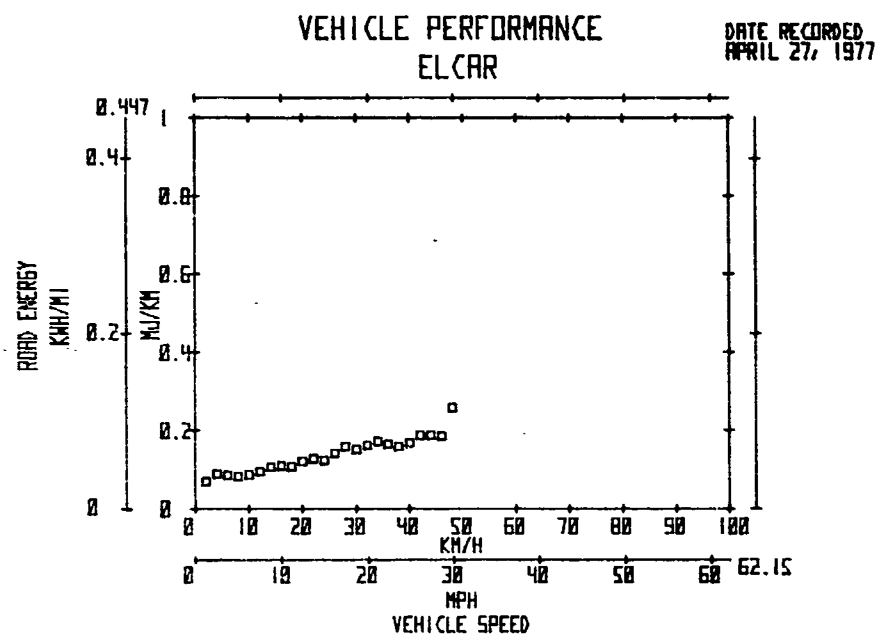


Figure 7. - Road energy as a function of speed.

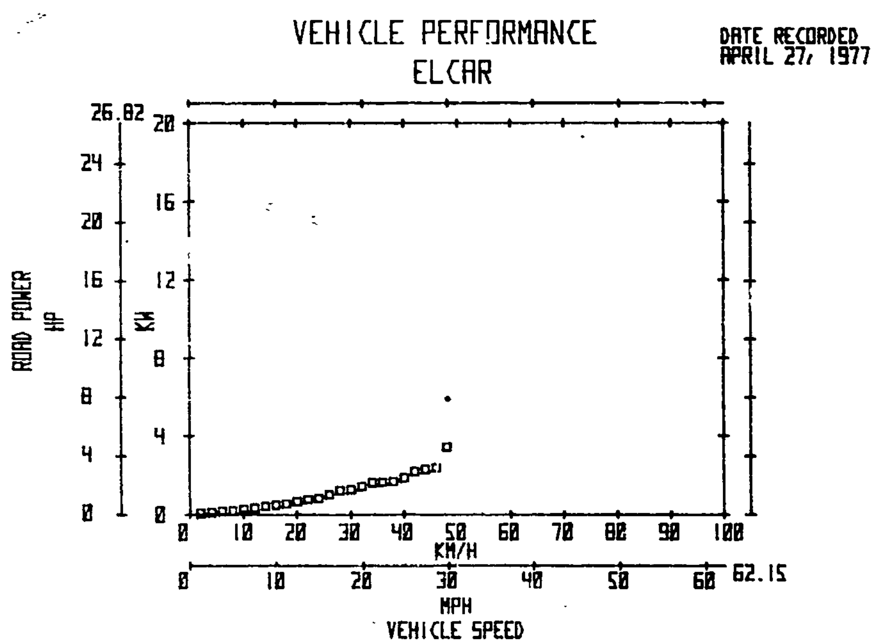


Figure 8. - Road power as a function of speed.

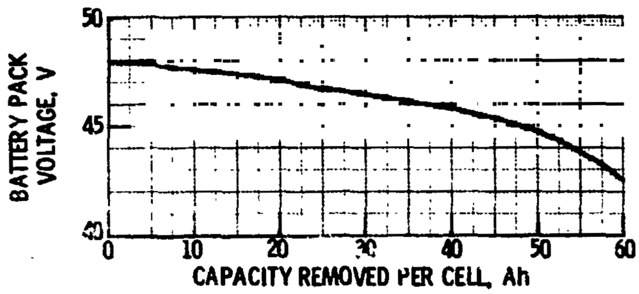
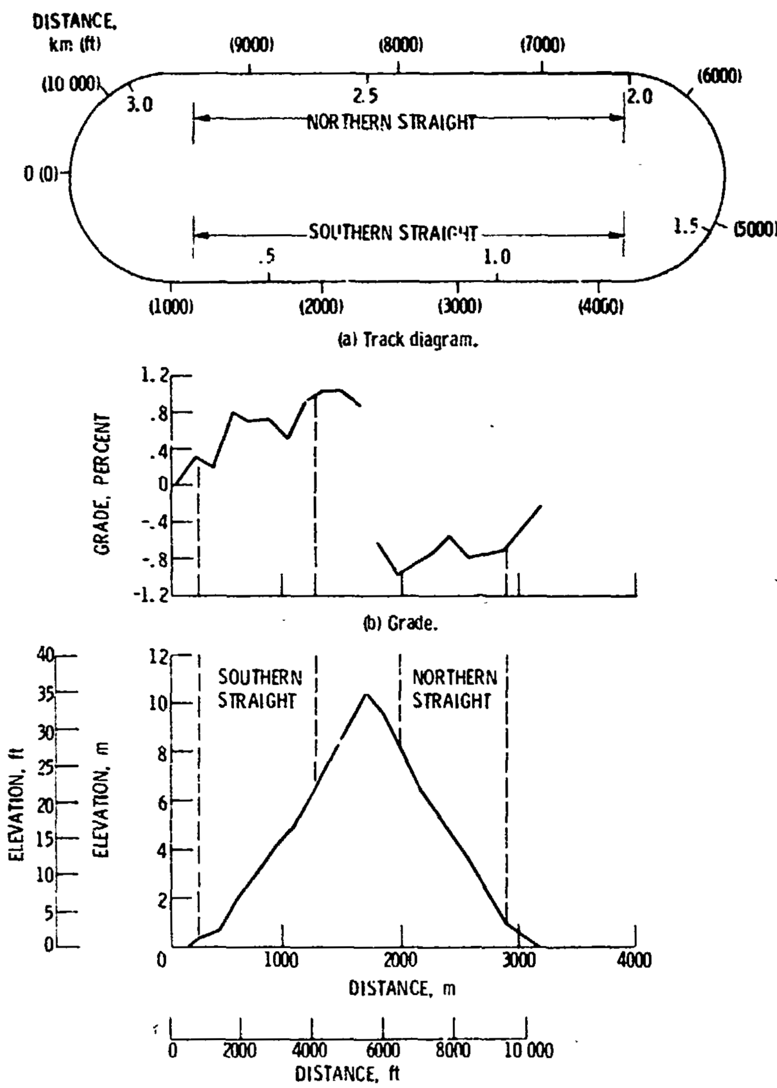


Figure 9. - Battery capacity for Zagato Elcar. (Test run with two 48-V subpacks in parallel.)



(a) Track diagram.

(b) Grade.

(c) Elevation.

Figure B-1. - Characteristics of Dynamic Science Test Track, Phoenix, Arizona.

1. Vehicle ______________________
2. Date received ______________________
3. Checked for damage - date ______________________
4. Wheel alignment - date ______________________
5. Battery checked and equalized - date ______________________
6. Curb weight determined, lbm ____________ Date ________
7. Gross vehicle weight, lbm ______________________
8. 300-Ampere test - date ______________________
9. Manufacturer's recommendations:
   Maximum speed, mph ______________________
   Tire pressures, psi: Front __________; Rear __________
   Driving procedures ______________________

Figure C-1. - Vehicle preparation check sheet.

Vehicle ______________, __________ mph range test, __________ gear

Driver Instructions:

1. Complete pretest checklist.
2. While on track recheck:
   Integrator - light on, in "operate" position, zeroed
   Speedometer - set on ____ mph center
   Distance - on, reset, lighted
   Attenuator - on, reset, lighted
3. At signal from control center accelerate moderately to ____ mph.
4. Maintain ____±1 mph with minimal accelerator movement.
5. When vehicle is no longer able to maintain ____ mph, brake moderately to full stop.
6. Complete post-test checklist and other documentation.

Recording:

1. Set oscillograph zeros at:

Channel	Zero, in.
3	3.0
4	4.5
6	5.0
10	.75
12	1.1
13	1.2
14	2.0

2. Record all channels on magnetic tape. Check inputs at beginning of test to verify recording.
3. Run cals on all channels.
4. Remove all channels from oscillograph except 3 and 4.
5. Start recording 15 s before start of test at oscillograph speed of 0.1 in/s and tape speed of ______ in/s.
6. After 15 min into test connect channels 6, 10, 12, 13, and 14 to oscillograph and record a burst at 100 in/s while vehicle is in chopper mode.
7. Remove channels 6, 10, 12, 13, and 14 from oscillograph and continue test at 0.1 in/s with channels 3 and 4 only.
8. Document all ambient conditions at beginning, once every hour, and at the end of the test. Items recorded shall include temperature, wind speed and direction, significant wind gusts, and corrected barometric pressure.

(a) Constant-speed test.

Figure C-2. - Test checklists.

Vehicle ____________________, ____________ cycle test, ____________ gear

Driver Instructions:

1. Complete pretest checklist.
2. While on track recheck:
   Integrator - light on, in "operate" position, zeroed
   Speedometer - set on ____ mph center
   Distance - on, reset, lighted
   Attenuator - on, reset, selector on 100
   Cycle timer - verify scheduled timing with stop watch
3. At signal from control center, perform cycle test using cycle timer as basis for determining length of each phase of performance cycle. Use programmed stop watch as backup device. Cycle consists of

   Accelerate to ______ mph in ______ s

   Cruise at ______ mph for ______ s

   Coast for ______ s

   Brake to complete stop in ______ s

   Hold in stop position for ______ s

   Repeat entire cycle until vehicle is unable to meet acceleration time. Moderately brake to a complete stop.
4. Complete post-test checklist and other documentation.

Recording:

1. Record all channels on magnetic tape at ______ in/s. Check all channels to verify input at beginning of test.
2. Record speed and distance on oscillograph at ______ in/s.
3. Start recording data 15 s before beginning test.
4. Document ambient conditions at beginning, once every hour, and at the end of the test. Items recorded shall include temperature, wind speed and direction, significant wind gusts, and corrected barometric pressure.

(b) Driving cycle test.

Figure C-2. - Concluded.

1. Record specific gravity readings after removing vehicle from charge, and disconnect charger instrumentation. Fill in charge data portion of data sheet from previous test. Add water to batteries as necessary, recording amount added. Check and record 5th wheel tire pressure and vehicle tire pressure.

2. Connect: (Connect alligator clips to instrumentation battery last)
   (a) Inverter to instrument battery
   (b) Integrator input lead
   (c) Integrator power to inverter
   (d) Starred (*) 5th wheel jumper cable
   (e) Cycle timer power and speed signal input cables. Check times.
   (f) Spin up and calibrate 5th wheel

3. Record test weight - includes driver and ballast with 5th wheel raised.

4. Turn on:
   (a) Inverter, motor speed sensor, thermocouple reference junctions, integrator, and digital voltmeter. Set integrator on "Operate."
   (b) Fifth wheel readout and switching interface units (2). (Select distance for expanded scale range.)

5. Tow vehicle onto track with 5th wheel raised.
   Precalibrations:
   Tape data system
   Oscillograph
   Reset:
   5th wheel distance
   Ampere-hour meter
   Thermocouple readout switches on "Record"
   Turn on thermocouple reference junctions.
   Lower 5th wheel. Set hub loading.

6. Be sure data sheet is properly filled out to this point. Check watch time with control tower.

7. Proceed with test.

Figure C-3. - Pretest checklist.

Vehicle ______________ Battery system ______________
Test ______________ Date ______________
Track data:
Driver ______________ Navigator ______________
Average pretest specific gravity ______________
Open-circuit voltage, V ______________
Tire pressure before test, psi:
Right front ___ Left front ___ Right rear ___ Left rear ___
Tire pressure after test, psi:
Right front ___ Left front ___ Right rear ___ Left rear ___
Fifth-wheel pressure, psi ________ (calibrated, ________ psi)

Weather:	Initial	During test	Final
Temperature, °F	____	____	____
Wind speed, mph	____	____	____
Wind direction	____	____	____
Pressure, in. Hg	____	____	____

Battery temperature, °F: Before ________ After ________
Motor temperature, °F: Before ________ After ________
Time: Start ______________ Stop ______________
Odometer reading, miles: Start _______ Stop _______
Current out, Ah ______ Current in (regenerative), Ah _____
Fifth wheel ______________
Basis for termination of tests ______________
____

Charge data:
Average post-test specific gravity ______________
Open-circuit voltage, V ______________
Charger used ______________
Charger input voltage, V ______________
Battery temperature, °F: Before charge ___ After charge ___
Power, kWh: Start ________ End ________ Total ________
Time: Start ______________ End ______________
Total charge time, min ______________
Current input, Ah ______________
Average specific gravity after charge ______________

Approval ______________

Figure C-4. - Track and charge data.

1. Record time immediately at completion of test. Turn off key switch.
2. Complete track data sheet:
   - (a) Odometer stop
   - (b) Ampere-hour integrator
   - (c) 5th wheel distance
   - (d) Read temperature
   - (e) Calibrate data system
   - (f) Record weather data
3. Turn off inverter, thermocouple reference junctions.
4. Disconnect 12-volt instrument battery red lead.
5. Raise 5th wheel.
6. Tow vehicle off track.
7. Start charge procedure (specific gravities).
8. Check specific gravity on instrument battery. If less than 1.220, remove from vehicle and charge to full capacity.
9. Check water level in accessory batteries. Add water as necessary.

Figure C-5. - Post-test checklist.

Vehicle ________ Test ________ Date ________

Test conditions:

Temperature, °F ________ Wind speed, mph ________ at ________

Barometer reading, in. Hg ________; Other ________

Test results:

Test time, h ________

Range, miles ________

Cycles ________

Current out of battery, Ah ________

Current into battery, Ah ________

Charge time, h ________

Power into battery, kWh ________

Magnetic tape:

No. ________; Speed, in/s ________

Comments ________

Figure C-6. - Test summary sheet.

Vehicle ______________ Test ______________ Date ______________

Engineer ______________

Reason for test (checkout, component check, scheduled test, etc.) ______________

Limitation on test (malfunction, data system problem, brake drag, etc.) ______________

Changes to vehicle prior to test (repair, change batteries, etc.) ______________

Other comments ______________

Evaluation of test:

Range, miles ______________

Current out, Ah ______________

Current in, Ah ______________

Power in, kWh ______________

Energy consumption, kWh/mile ______________

Was planned driving cycle followed? ______________

General comments ______________

Figure C-7. - Engineer's data sheet.

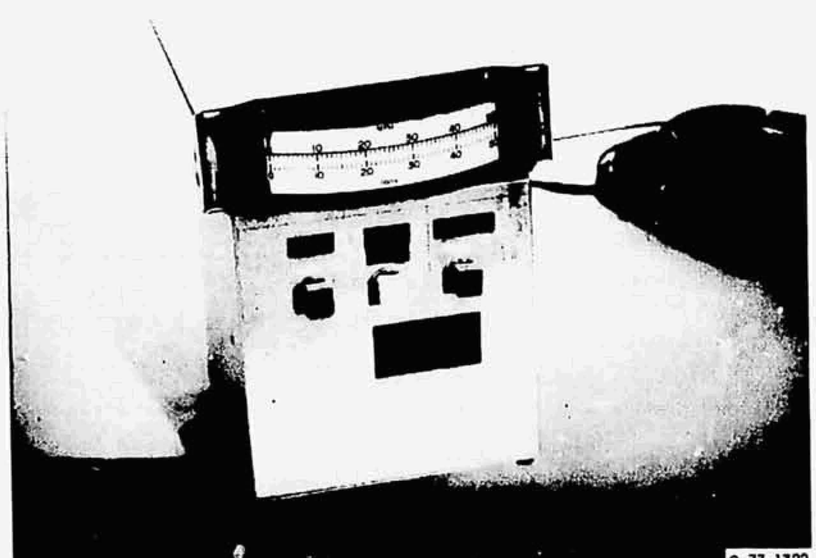


Figure C-8. - Cycle timer.