CONS/1011-2
NASA TM-73757

(NASA-TM-73757) BASELINE TESTS OF THE C. H. WATERMAN DAF ELECTRIC PASSENGER VEHICLE (NASA) 113 p HC A06/MF A01 CSCL 13F

N78-17942

Unclas
G3/85 05395

BASELINE TESTS OF THE C. H. WATERMAN DAF ELECTRIC PASSENGER VEHICLE

Noel B. Sargent, Edward A. Maslowski,
Richard F. Soltis, and Richard M. Schuh
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

October 1977

Prepared for
DEPARTMENT OF ENERGY
Division of Transportation Energy Conservation
Under Interagency Agreement EC-77-A-31-1011

117

1 Report No	2 Government Accession No	3 Recipient's Catalog No
NASA TM-73757		

4 Title and Subtitle	5 Report Date
BASELINE TESTS OF THE C. H. WATERMAN DAF ELECTRIC PASSENGER VEHICLE	October 1977
	6 Performing Organization Code
7 Author(s) Noel B. Sargent, Edward A. Maslowski, Richard F. Soltis, and Richard M. Schuh	8 Performing Organization Report No E-9388
9 Performing Organization Name and Address National Aeronautics and Space Administration Lewis Research Center Cleveland, Ohio 44135	10 Work Unit No
	11 Contract or Grant No
	13 Type of Report and Period Covered Technical Memorandum
12 Sponsoring Agency Name and Address Department of Energy Division of Transportation Energy Conservation Washington, D.C. 20545	14 Sponsoring Agency ~~Code~~ Report No. CONS/1011-2

15 Supplementary Notes

Prepared under Interagency Agreement EC-77-A-31-1011.

16 Abstract

The C. H. Waterman DAF sedan, an electric vehicle manufactured by C. H. Waterman Industries, Athol, Massachusetts, was tested at the Dynamic Science Test Track in Phoenix, Arizona, as part of an Energy Research and Development Administration (ERDA) project to characterize the state-of-the-art of electric vehicles. The Waterman vehicle performance test results are presented in this report. The Waterman is a converted four-passenger DAF 46 sedan. It is powered by sixteen 6-volt traction batteries through a three-step contactor controller actuated by a foot throttle to change the voltage applied to the 6.7-kW (9-hp) motor. The braking system is a conventional hydraulic braking system

17 Key Words (Suggested by Author(s))	18 Distribution Statement
Electric vehicle Car Test and evaluation Battery	Unclassified - unlimited STAR Category 85 ERDA Category UC-96

19 Security Classif (of this report)	20 Security Classif (of this page)	21 No of Pages	22 Price*
Unclassified	Unclassified	116	A06

* For sale by the National Technical Information Service, Springfield, Virginia 22161

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.

CONTENTS

BASELINE TESTS OF THE C. H. WATERMAN DAF ELECTRIC PASSENGER VEHICLE

Noel B. Sargent, Edward A. Maslowski,
Richard F. Soltis, and Richard M. Schuh

Lewis Research Center

SUMMARY

The C. H. Waterman DAF sedan, an electric passenger vehicle manufactured by C. H. Waterman, Athol, Massachusetts, was tested at the Dynamic Science Test Track in Phoenix, Arizona, between January 17 and March 18, 1977. The tests are part of an Energy Research and Development Administration (ERDA) project to characterize the state-of-the-art of electric vehicles. The Waterman vehicle performance test results are presented in this report.

The Waterman vehicle is a four-passenger DAF 46 sedan that has been converted to an electric vehicle. It is powered by sixteen 6-volt traction batteries through a three-step contactor controller actuated by a foot throttle to change the voltage applied to the 6.7-kilowatt (9-hp) motor. The braking system is a conventional hydraulic braking system. Regenerative braking was not provided.

All tests were run at the gross vehicle weight of 1365 kilograms (3010 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)	95	59	3.0	0.27	0.12	0.98	0.44
50 km/h (31 mph)	93	58	4.0	.29	.13	.78	.35
Schedule B	67	42	---	----	----	----	----

The Waterman DAF was able to accelerate from 0 to 32 kilometers per hour (0 to 20 mph) in 14 seconds and from 0 to 48 kilometers per hour (0 to 30 mph) in 29 seconds. The gradeability limit was 18 percent.

Measurements were made to assess the performance of the vehicle components. The performance was as follows:

Charger efficiency over a complete charge cycle, percent	80 to 93
Battery efficiency with 20 percent overcharge, percent	63
Controller efficiency, percent	>99
Motor efficiency at constant speed, percent	73 to 80

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, is conducting 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. This procedure is based on the Society of Automotive Engineers (SAE) J227a procedure (ref. 1). Seventeen electric vehicles have been tested under this phase of the program, 12 under the direction of the Lewis Research Center, 4 under the direction of MERADCOM, and 1 by the Canadian government.

The assistance and cooperation of C. H. Waterman, the vehicle manufacturer, 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.

ORIGINAL PAGE IS
OF POOR QUALITY

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 Waterman DAF are vehicle speed, range at constant speed, range over stop-and-go driving schedules, maximum acceleration, gradeability, gradeability limit, road energy consumption, road power, indicated energy consumption, braking capability, battery charger efficiency, battery characteristics, controller efficiency, and motor efficiency.

TEST VEHICLE DESCRIPTION

The C. H. Waterman DAF sedan is a converted DAF 46 sedan propelled by a DC series electric motor and powered by sixteen 6-volt traction batteries. A three-step contactor controller actuated by a foot throttle changes the voltage applied to the 6.7-kilowatt (9-hp) motor. A two-position gearshift selector is provided for forward and reverse. The vehicle is accelerated by depressing the accelerator through the three contactor steps and then actuating the overdrive switch on the dash. This switch applies power to an air pump that compresses a variable-pulley sheave transmission to increase the speed of the vehicle. The vehicle is shown in figure 1 and described in detail in appendix A. The

120-volt AC battery charger on board the vehicle provided charge to both the traction batteries and the accessory battery. The vehicle manufacturer specifies 10 hours to completely recharge fully discharged batteries, but for the track tests a longer period was used to assure complete recharging. No regenerative braking was provided on this vehicle. The controller, charger, and front battery pack are shown in figure 2.

INSTRUMENTATION

The C. H. Waterman DAF vehicle was instrumented to measure vehicle speed and range; battery current; motor current, voltage, and speed; temperatures of the motor frame and battery case; and battery charger power. Most of these data were telemetered to a central instrumentation facility, where they were recorded on magnetic tape. The telemetry system is shown in figure 3 and described in appendix B.

A schematic diagram of the electric propulsion system with the instrumentation sensors is shown in figure 4. 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 AC motor. The accuracy of the distance and velocity readings was within ± 0.5 percent of the readings. Distance and velocity were recorded on magnetic tape through the telemetry system.

The integrated battery current was measured for the battery pack with a current shunt and an on-board current integrator. It was recorded manually after each test. This measurement provides the ampere-hours delivered by one-half of the battery pack. The current integrator is a Model SHR-C3 Curtis current integrator and was calibrated periodically to within ± 1 percent of reading.

Motor current, motor voltage, and motor speed were measured to determine motor performance. A 500-ampere current shunt was used to measure motor current. Motor shaft speed was measured by means of a light-reflecting photoelectric sensor that detects the passage of a strip of reflecting paint on the flywheel. These measurements were telemetered and recorded on magnetic tape. Temperatures on the motor and on both front and rear battery packs were monitored and continuously recorded on magnetic tape during the tests. 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. The power for the telemetry system was obtained from a battery power pack described in appendix B.

All instruments were calibrated periodically. The integrators and strip-chart recorders were calibrated with a Hewlett-Packard Model 6920 B meter calibrator, which has an accuracy of 0.2 percent of reading 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 current measurement used a 500-ampere current shunt in all the tests except in one series. In these tests to measure charger efficiency, a laboratory-type wattmeter with Hall-effect current sensors manufactured by Ohio Semitronics, Inc., was used. The energy delivered to the charger was measured with a General Electric 1-50A single-phase residential kilowatt-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 C. When the vehicle was delivered to the test track, the pretest checks described in appendix D 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 D). All tests were run in accordance with ERDA Electric and Hybrid Vehicle Test And Evaluation Procedure ERDA-EHV-TEP (appendix E) at the gross weight of the vehicle, 1365 kilograms (3010 lbm).

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 50 kilometers per hour (31 mph) for the Waterman DAF.

Range tests at constant speeds were run at 40 and 50 kilometers per hour (25 and 31 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 at both speeds.

Range Tests under Driving Schedules

Only the 32-kilometer-per-hour (20-mph), schedule B stop-and-go driving cycle, shown in figure 5, was run with this vehicle. The Waterman DAF was unable to accelerate rapidly enough to meet schedule C. A complete description of cycle tests is given in appendix E. 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 D. 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 C, fig. C-1). Coast-down data were taken after the acceleration test with the transmission in neutral and with fully charged batteries in order to start the coast-down run from the maximum attainable vehicle speed.

Braking Tests

Braking tests on the vehicle were conducted

(1) To determine the minimum stopping distance in a straight-line emergency stop

(2) To determine the controllability of the vehicle while braking in a turn on both wet and dry pavement

(3) To determine the brake recovery after being driven

through 0.15 meter (6 in.) of water at 8 kilometers per hour (5 mph) for 2 minutes

(4) To determine the parking brake effectiveness on an incline

Instrumentation used during the braking test included a fifth wheel programmed to determine stopping distance, a brake pedal force transducer, and a decelerometer. A complete description of the braking tests is given in the discussion of test results and in appendix E.

Tractive Force Tests

The maximum grade climbing capability of the test vehicle was determined from tractive force tests by towing a second vehicle. The driver of the towed vehicle, by applying the footbrake, maintained a speed of about 3 kilometers per hour (2 mph) while the test vehicle was being driven with a wide-open throttle. The force was measured by a 13 000-newton (3000 lbf) load cell attached to the tow chain between the vehicles. The test was run with the batteries fully charged and 40 and 80 percent discharged.

Charger Efficiency Tests

Two methods were used to determine charger efficiency as a function of charge time. In the first method a residential kilowatt-hour meter was used to measure input power to the charger by counting rotations of the disk and applying the meter manufacturer's calibration factor. The charger output power was determined by multiplying the average value of current by the average value of voltage. Residential kilowatt-hour meters are calibrated for sinusoidal waves only. The error in measuring input power depends on the wave shape and may be as high as 5 percent. The method of determining output power is correct only when either the voltage or the current is a constant during each charging pulse. The battery voltage does change during each charging pulse, which introduces a small error. The current shunts used to measure current are inaccurate for pulsing current. The error depends on frequency and wave shape and may exceed 10 percent.

In the other method used for determining charger efficiency a 50-kilowatt power meter was used on both the input and output of the charger and a Hall-effect current probe was used for current measurements. To minimize errors, the same meter and current probe were used for both the input measurement and the output measurement. The average power measured was about 4 percent of full scale.

The influence of these inaccuracies on the determination of charger efficiency is discussed in the component section of this report.

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 58 kilometers per hour (36 mph) for this vehicle. This differs from the maximum speed used in the range tests.

Two 40-kilometer-per-hour (25-mph), five 50-kilometer-per-hour (31-mph), and three schedule B range tests were run. All the test results are shown in table I. Two of the 50-kilometer-per-hour-test results were lost because of vehicle problems and one of the schedule B test results because of driver error. All the remaining range test results were within ±5 percent of the mean.

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 6 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 7 and table III.

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

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

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 grade the Waterman DAF can negotiate as a function of speed is shown on figure 8 and table IV.

Gradeability Limit

Gradeability limit is defined by the SAE J227a procedure as the maximum grade on which the vehicle can just move forward. The limit was determined by measuring the tractive force with a load cell while towing a second vehicle at about 3 kilometers per hour (2 mph). It was calculated from the equations

$$\text{Gradeability limit in percent} = 100 \tan \left(\sin^{-1} \frac{P}{9.8\ W}\right)$$

in SI units

or

$$\text{Gradeability limit in percent} = 100 \tan \left(\sin^{-1} \frac{P}{W}\right)$$

in U.S. customary units

where

P tractive force, N (lbf)

W gross vehicle weight, kg (lbm)

The Waterman DAF was capable of exerting the following tractive forces for three states of battery discharge:

(1) Fully charged, 2400 newtons (540 lbf)

(2) 40 Percent discharged, 2200 newtons (495 lbf)

(3) 80 Percent discharged, 2160 newtons (485 lbf)

At a vehicle weight of 1365 kilograms (3010 lbm) the resulting gradeability limits were

(1) Fully charged, 18.2 percent

(2) 40 Percent discharged, 16.6 percent

(3) 80 Percent discharged, 16.3 percent

Continuous belt slippage in the DAF variable transmission was noted during these tests. This slippage lowered the coefficient of friction between the belt and the pulley so that the gradeabilities were reduced at very low speeds. The vehicle was easily driven up the 20 percent brake slope at a constant speed of 16 kilometers per hour (10 mph) without belt slippage. The gradeability limit is reduced to 18 percent at starting and increased to a maximum near 10 kilometers per hour, as shown in figure 8.

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 portion of the transmission rotating when in neutral. 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.

Road energy consumption E_n was calculated from the following equations:

$$E_n = 2.78\times10^{-4} W \frac{V_{n-1} - V_n}{t_n - t_{n-1}}, \text{ MJ/km}$$

or

$$E_n = 9.07\times10^{-5} W \frac{V_{n-1} - V_n}{t_n - t_{n-1}}, \text{ kWh/mile}$$

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 9 and table V.

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 from the differential, the drive shaft, and a portion of the transmission. 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:

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

or

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

The results of road power calculations are shown in fig. 10 and table VI.

Indicated Energy Consumption

The vehicle indicated energy consumption 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 after each range test. Some overcharge of the batteries was usually required in order to assure that all battery cells were fully charged and that the pack was equalized. The reported energy usage may be higher than would be experienced with normal vehicle field operation. Indicated energy consumption as a function of vehicle speed is presented in figure 11 and table VII for the constant-speed tests.

Braking Capability

Simplified braking capability tests were conducted according to the procedure outlined in appendix E in order to provide a preliminary evaluation of the vehicle's braking capabilities. The procedure also includes tests for handling at ERDA's direction, but they were not conducted on this vehicle.

Straight-line stops. - Six straight-line stops from 50 kilometers per hour (31 mph) were made, three from each direction. Stopping distance varied from 15.2 meters (50 ft) to 16.8 meters (55 ft).

Stops on a curve. - Three stops were made going into a 0.3-g curve from 50 kilometers per hour (31 mph) on dry pavement turning right, and three stops were made on the same curve turning left. No difficulties were encountered in stopping within the 3.6-meter (12-ft) lane. The stopping distance varied from 17.4 meters (57 ft) to 18.6 meters (61 ft). The tests were repeated in a 0.2-g turn on wet pavement. Again the vehicle stopped smoothly with no problems. The stopping distances varied from 16.8 meters (55 ft) to 18.3 meters (60 ft).

Wet brake recovery. - Three baseline stops were made from 48 kilometers per hour (30 mph) with dry brakes, decelerating at 3 meters per second squared (10 ft/sec^2). The average pedal force was 214 newtons (48 lbf). After driving through 0.15 meter (6 in.) of water at 8 kilometers per hour (5 mph) for 2 minutes, the tests were repeated. The first stop was made with a pedal force of 374 newtons (84 lbf). The brakes had fully recovered on the fifth stop.

Parking brake. - Tests were conducted to determine parking brake effectiveness. The vehicle did not pass the parking brake test the first time. The brakes were adjusted and the tests were repeated. After adjustment, the braking force required to hold the vehicle on a 30-percent slope was 156 newtons (35 lbf) facing uphill and 133 newtons (30 lbf) facing downhill, with the force being applied 3.8 centimeters (1.5 in.) from the top of the brake handle. No slippage during the 5-minute hold was observed with the parking brake set as described. The test was run twice in each attitude.

COMPONENT PERFORMANCE AND EFFICIENCY

Battery Charger

The C. H. Waterman battery charger consists of a transformer that has a tapped primary and two center-tapped secondary windings. One of the secondaries is used to charge the traction batteries. The other secondary is used to charge the 12-volt accessory battery. Both of the center-tapped secondaries are connected through diodes to form full-wave rectifiers. The outputs of each system may be simultaneously adjusted by means of the primary tap.

The battery charger efficiency test data are presented in table VIII and in figure 12. The indicated efficiencies of the charger, as calculated from the readings on the residential kilowatt-hour meter and the average values of charger output voltages and amperes, are up to 10 percent less than the efficiencies that were calculated using wattmeter readings. Which set of values is more nearly correct has not been determined. Since the power efficiency is fairly constant over the entire time period, the energy efficiency is approximately equal to the average of the power efficiencies.

The total amount of energy that is delivered to the battery depends not only on the charger efficiency, but also on the system used to terminate the charge. The C. H. Waterman charger uses a timer set by the operator to terminate the charge and a switch on the transformer primary to adjust the charging current. The charging current is controlled by the difference between the applied voltage and the battery voltage, divided by the circuit impedance. Slight changes in the applied voltage or slight variations in the battery voltage (due to temperature, age, etc.) can drastically affect the charging current and the time required to attain full charge. Consequently, the amount of energy that is delivered to the battery is largely determined by the judgement of the operator. During the track tests the battery was always purposely overcharged.

Batteries

Manufacturer's data. - The batteries supplied with the C. H. Waterman DAF vehicle were Electric Storage Battery (ESB) Incorporated Exide or Willard EV-106 electric vehicle batteries. The EV-106 is a 6-volt, three-cell module rated at 106 minutes discharge at a current of 75 amperes to a voltage cutoff of 1.75 volts per cell at a temperature of 25° C (77° F). Dimensional specifications as supplied by battery manufacturers are shown in table IX.

Battery manufacturer's discharge data are presented in figures 13 and 14. Figure 13 gives the relationship of discharge current and voltage to the length of time the battery is able to deliver this current. As shown, the battery can deliver 10 amperes for 20 hours, or 200 ampere-hours, but it can deliver 250 amperes for only 0.37 hour, or 92.5 ampere-hours. At a discharge current of 10 amperes, the mean cell voltage is 2.0 volts; at a discharge current of 250 amperes, the mean cell voltage drops to 1.5 volts during the discharge period. The batteries rated capacity is about 15 percent lower than the capacity shown in figure 13, and this rated capacity is what is used to evaluate the battery.

Figure 14 gives the battery manufacturer's relationship of specific power to the specific energy available from a three-cell module. At a low specific power of 2 watts per kilogram the available energy is 0.15 megajoule per kilogram (41.7 Wh/kg). At a high specific power of 40 watts per kilogram (18 W/lbm), the available energy decreased to 0.052 megajoule per kilogram (14.6 Wh/kg). At the manufacturer's rated discharge rate of 75 amperes, which is equivalent to 14 W/kg, the available specific energy is 0.096 megajoule per kilogram (26.7 Wh/kg).

Battery acceptance. - Before road testing was started, the batteries supplied by the vehicle manufacturer were tested for battery capacity and terminal integrity as specified in appendix E.

The capacity check (fig. 15(a)) was performed on the batteries by means of a constant-current load bank. Since the measured capacity was 118 ampere-hours at a discharge current of 75 amperes, 89 percent of the manufacturer's rated capacity, the battery was acceptable. As shown in the figure the battery voltage at the start of discharge was 96 volts (2.0 volts per cell (VPC)) and decayed gradually to 84 volts (1.75 VPC) at the end of the test.

The 300-ampere discharge test was run with a resistor load bank. As shown in figure 15(b) the battery voltage quickly fell to 81 volts (1.7 VPC) at a discharge current of 310 to 325 amperes and remained at close to that voltage level throughout the test. At the end of the 5-minute test, the terminal temperature as measured by temperature-sensitive tape did not exceed 82° C (180° F). As this was less than 60° C above ambient, the battery system was within specifications.

Battery performance at constant vehicle speed. - During the road tests, motor current and voltage were constantly monitored. The vehicle employs a contactor speed controller, which switches voltage applied to the motor from 0 to 12 to 24 to 48 volts at the direction of the driver. During the constant-speed tests, the motor voltage was either 48 volts (on) or zero (off), so that motor power is determined by the duty cycle (the ratio of the time 48 volts was applied to the motor to the total time.) In contactor control systems, the motor current is equal to the battery current. The motor voltage is equal to battery voltage during the "on" period, but during the "off" period, battery voltage rises, due to depolarization, close to open-circuit voltage and motor voltage goes to zero. Motor power, which is the instantaneous product of voltage and current, is equal to battery power.

Presented in figure 16 are the battery characteristics during the 40-kilometer-per-hour (25-mph) range test run on 1/25/77 and the 50-kilometer-per-hour (31-mph) range test run on 1/27/77. The average battery current, voltage, and power during the first 25 percent of the vehicle's range are shown in figure 16(a). Similar battery peformance data during the last 25 percent of the vehicle's range are shown in figure 16(b). Battery power decreases toward the end of the test, probably due to the reduced power requirements as the temperature of the mechanical drive train components, tires, and associated lubricants increases during the test.

Table X contains battery performance data for the 40- and 50-kilometer-per-hour (25- and 31-mph) range tests for the first and last 25 percent of the tests. A 1.97-volt-per-cell open-ciruit voltage $\overline{V}_{OC}$ for the batteries was assumed in order to calculate the battery voltage. The equations used to generate the data in table X are

$$\overline{D}_C = \frac{\overline{I}_M \overline{V}_M}{\overline{P}_M}$$

and

$$\overline{V}_B = \overline{V}_M + \overline{V}_{OC} (1 - D_C)$$

where $\overline{V}_{OC}$ is the average open-circuit voltage. (The symbols are defined in table X.) As shown, the product of average voltage and average current gives the average power corrected by the duty cycle.

Battery performance over a driving cycle. - The vehicle speed and average battery current and power for the 3rd and 200th cycles of a schedule B test are shown in figures 17 and 18. Not shown in the figures are the large battery transients that occurred during each phase of the cycle. These transients, typically of 1 or 2 seconds duration, occurred while the driver was attempting to adjust vehicle speed to meet driving schedule requirements. Large transients were also present during the acceleration phase of the test cycle. Currents as high as 350 amperes have been measured.

Battery performance at maximum acceleration. - Battery performance data at selected times during the maximum acceleration test for three depths of battery discharge are presented in table XI. The power at 20 seconds is substantially higher than the power at 10 and 50 seconds because the vehicle was undergoing a gear change from low to overdrive condition at this time.

General battery performance. - Battery data for the driving tests are shown in table XII. The electrolyte specific gravities range from 1.290 to 1.295 for the fully charged battery and from 1.120 to 1.150 for the fully discharged battery. The ampere-hour overcharge varies from 11 percent to 38 percent. While the overcharge is necessary to equalize the cells in order to assure full charge from every cell, this is not the best way to minimize energy consumption. A charge cycle that results in only a 10-percent overcharge is more desirable.

The battery temperature had a tendency to increase from ambient at the start of the test to about 14° C (25° F) above ambient at the end of test.

Charging and battery efficiency. - One battery charging phase was fully analyzed to determine battery efficiency. This charge followed the 50-kilometer-per-hour (31-mph) constant-speed test run on 1/27/77.

The battery charger voltage, current, and power are presented in figure 19 as a function of time. The large increase in current at 2.5 hours is due to a normal readjustment of the charger in order to reduce total charging time.

Total energy input to the battery during charging was 18.3 kilowatt-hours; the energy removed during the 50-kilometer-per-hour (31-mph) range test was 11.5 kilowatt-hours. The battery energy efficiency is therefore 63 percent. However, as shown in table XII, the ampere-hour overcharge was 20 percent for this test. The overcharge is necessary to insure equalization of the battery and to maximize the vehicle performance in subsequent tests. A more desirable overcharge would be 10 percent. This would result in a battery energy efficiency of about 70 percent.

Controller

The C. H. Waterman DAF vehicle is controlled by battery-switching contactors. The battery modules are connected in 12-, 24-, or 48-volt arrangements by energizing the proper contactors. Under all operating conditions, the voltage drop across the contacts is less than 100 millivolts and the coil dissipation is less than 100 watts. Consequently, the controller efficiency is greater than 99 percent. In a vehicle the operation of the controller varies depending on the type of test being run. In maximum acceleration tests, 48 volts is applied to the motor continuously. In the constant-speed tests the driver closes the contactors, applying 48 volts to the motor and accelerating the vehicle until it exceeds the target speed. Then the driver opens the contactors, disconnecting the motor from the power source and allowing the vehicle to coast down to a speed below target speed. The driver then recloses the contactors and repeats the cycle. During these constant speed tests the speed actually varied ±1.6 kilometers per hour. The duty cycle shown in table X indicates the percentage of time that the contactors are closed.

Motor

The C. H. Waterman motor is a conventional DC series-wound traction motor originally designed for use in industrial trucks. The motor was manufactured by the Prestolite Electrical Division of Eltra Corp. A data sheet dated November 15, 1971, and cold-performance curves (figure 20) dated February 15, 1968, for this motor were supplied by C. H. Waterman. The data sheet gives the 1-hour rating of the motor as 6.7 kilowatts (9 hp) at 1630 rpm, 250 amperes, and 36 volts. The motor is Class H insulated and has an internal cooling fan. The combined resistance of the armature and series field is given as 0.0124 ohm.

Figure 20 indicates that at 36 volts the motor efficiency rises from zero at no load to a peak of 80 percent at 75 amperes and falls off to 62 percent at 575 amperes. Since the vehicle operates at nominal voltage levels of 24 and 48 volts, the curves are not directly applicable. The speed and horsepower curves may be approximately scaled in proportion to the voltage change. When the curves are scaled to 48 volts, the scaling error will give values of speed and horsepower that are less than the true values. Consequently, the efficiency at 48 volts should be higher than the values shown.

Representative average values of motor current for the constant-speed test are listed in table X. By dividing the average value of motor current by the duty cycle, representative values of the motor current during the period when the contactors were closed were obtained. For the 40-kilometer-per-hour test the values range from about 200 amperes to about 310 amperes. The corresponding range for the 50-kilometer-per-hour test is 190 to 250 amperes. In the interval from 200 to 300 amperes, the motor efficiency at 36 volts varied from 73 percent to 77 percent. Consequently, the motor efficiency at 48 volts was estimated to vary from about 75 percent to 80 percent.

Plots of speed, current, voltage, and power for two cycles of SAE J227a driving schedule B are shown in figure 21. Cycle 2 is near the start of the test and cycle 201 is near the end of the test. The motor current, voltage and power from the acceleration tests are also plotted in figure 22 as a function of gradeability for the high gear ratio at three depths of battery discharge. These plots show that the currents are in the same general range as in the constant-speed tests, and so approximately the same values of efficiency are expected.

VEHICLE RELIABILITY

No major problems were encountered that prevented completion of the tests, but several problems occurred that delayed the tests. These problems were related to the control of the charger and battery. Sometimes the 48-volt contactor used to series the battery packs for charging would fail to function, thus not allowing the batteries to charge. Since the contactors are open to the environment, it is suspected that dirt particles between the contactor armature and the coil caused this problem. The contactor control operated normally during driving on all tests except one. During one of the 50-kilometer-per-hour (31-mph) range tests, only half of the battery pack discharged; the cause of this has not definitely been determined. It could be related to a short to ground in a diode caused by a cracked insulating washer. After this was replaced, the batteries discharged normally during the remaining tests.

DRIVER REACTION AND VEHICLE SERVICEABILITY

The vehicle is a comfortable, well-handling vehicle at constant speed. However, acceleration is very slow and can be jerky when rapid changes in voltage occur with the contactor control.

The manually switchable high-low charge range of the Waterman charger requires attention to battery charging. The operation of this charger is also very dependent on line input voltage. Longer charge times are required if line voltage is low. The batteries were all relatively easy to service (i.e., by adding water and servicing the terminals), except for the one in the front pack that is located close to the steering arm. The battery post was modified by sawing approximately one third of the post away to provide sufficient clearance between the two.

REFERENCE

1. Society of Automotive Engineers: Electric Vehicle Test Procedure - SAE J227a. Feb. 1976.

TABLE I. - SUMMARY OF TEST RESULTS FOR WATERMAN DAF[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	Remarks
1/25/77	40	9.7	14	95.7	---	146	202	95	1.00	---
1/26/77	40	4.8 - 8.0	12	93.6	---	142	192	90	.96	---
1/27/77	50	4.8	12	92.7	---	133	160	76	.83	---
2/3/77	50	---	---	91.7	---	---	---	---	---	No data taken (controller checkout)
2/9/77	50	11.3	14	93.6	---	127	141	69	.74	---
3/12/77	B	0 - 8.0	17	36.4	102	67	115	58	---	Driving errors
3/13/77	B	16.1	21	68.4	201	122	128	62	.89	Wind gusts
3/18/77	B	3.2 - 9.7	14	64.7	184	---	150	75	1.14	Integrator malfunction

(b) U.S. customary units

Test date	Test condition (constant speed, mph; or driving schedule)	Wind velocity, mph	Temperature, °C	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	Remarks
1/25/77	25	6	58	59.5	---	146	202	27	0.45	---
1/26/77	25	3 - 5	53	58.2	---	142	192	25	.43	---
1/27/77	31	3	54	57.6	---	133	160	21	.37	---
2/3/77	31	---	---	57.0	---	---	---	---	---	No data taken (controller checkout)
2/9/77	31	7	58	58.2	---	127	141	19	.33	---
3/12/77	B	0 - 5	63	22.6	102	67	115	16	---	Driving errors
3/13/77	B	10	70	42.5	201	122	128	17	.40	Wind gusts
3/18/77	B	2 - 6	57	40.2	184	---	150	21	.51	Integrator malfunction

[a]Problems encountered during 50-km/h (31-mph) range tests:

(1) On 2/1/77, parking brake was found to be partially on and test was aborted.

(2) On 2/2/77, only half the batteries were discharged at end of test (59.5 km; 37 miles) due to controller malfunction.

TABLE II. - ACCELERATION TIMES FOR WATERMAN DAF

Time, s	Amount of discharge, percent					
	0		40		80	
	Vehicle speed					
	km/h	mph	km/h	mph	km/h	mph
1	5.5	3.4	4.3	2.7	8.8	5.5
2	12.2	7.6	11.7	7.3	13.4	8.3
3	16.1	10.0	15.6	9.7	15.8	9.8
4	18.5	11.5	17.7	11.0	17.5	10.9
5	20.3	12.6	19.3	12.0	19.0	11.8
6	21.4	13.3	20.6	12.8	20.3	12.6
7	22.8	14.2	21.7	13.5	21.4	13.3
8	24.0	14.9	22.8	14.2	22.2	13.8
9	24.9	15.5	24.0	14.9	23.2	14.4
10	25.9	16.1	24.6	15.3	24.1	15.0
12	27.8	17.3	26.4	16.4	25.7	16.0
14	29.4	18.3	28.2	17.5	27.4	17.0
16	32.0	19.9	30.1	18.7	29.0	18.1
18	35.1	21.8	32.8	20.4	31.4	19.5
20	38.6	24.0	36.0	22.4	34.4	21.4
22	41.8	26.0	39.1	24.3	37.5	23.3
24	44.2	27.5	41.5	25.8	39.7	24.7
26	46.3	28.8	43.4	27.0	41.7	25.9
28	47.9	29.8	45.1	28.0	43.1	26.8
30	49.1	30.5	46.3	28.8	44.7	27.8
32	50.5	31.4	47.3	29.4	45.9	28.5
34	51.3	31.9	48.3	30.0	46.7	29.0
36	52.2	32.3	48.9	30.4	47.5	29.5
38	52.8	32.8	49.6	30.8	48.1	29.9
40	53.4	33.2	50.2	31.2	48.9	30.4
42	54.1	33.6	50.5	31.4	49.4	30.7
44	54.5	33.9	51.0	31.7	49.9	31.0
46	55.0	34.2	51.3	31.9	50.4	31.3
48	55.3	34.4	51.6	32.1	50.7	31.5
50	55.8	34.7	52.9	32.3	51.2	31.8
52	56.2	34.9	52.3	32.5	51.3	31.9
54	56.6	35.2	52.6	32.7	51.8	32.2

TABLE III. - ACCELERATION CHARACTERISTICS OF WATERMAN DAF

Vehicle speed		Amount of discharge, percent					
km/h	mph	0		40		80	
		Vehicle acceleration					
		m/s^2	mph/s	m/s^2	mph/s	m/s^2	mph/s
2.0	1.2	1.3	2.8	1.5	3.4	1.7	3.9
4.0	2.5	1.7	3.7	2.1	4.9	2.3	5.3
6.0	3.7	2.1	4.7	2.6	5.8	2.7	6.1
8.0	5.0	2.5	5.6	2.7	6.0	2.7	6.1
10.0	6.2	2.9	6.5	2.3	5.2	2.2	4.9
12.0	7.5	2.3	5.1	1.7	3.8	1.5	3.4
14.0	8.7	1.4	3.1	1.3	2.8	1.0	2.3
16.0	9.9	.9	2.1	.9	2.0	.7	1.5
18.0	11.2	.7	1.5	.6	1.4	.5	1.1
20.0	12.4	.5	1.1	.4	1.0	.4	.8
22.0	13.7	.4	1.0	.4	.8	.3	.7
24.0	14.9	.4	.8	.3	.8	.2	.6
26.0	16.1	.3	.7	↓	.7	.2	.5
28.0	17.4	↓	.6	↓	.6	.2	.6
30.0	18.7	↓	.7	↓	.6	.3	.6
32.0	19.9	↓	.7	↓	.7	.4	.8
34.0	21.1	↓	.7	.4	.9	↓	1.0
36.0	22.4	.4	1.0	.5	1.1	↓	1.0
38.0	23.6	.5	1.2	.5	1.1	↓	.9
40.0	24.9	.5	1.2	.5	1.1	↓	.8
42.0	26.1	.5	1.2	.4	1.0	.3	.7
44.0	27.4	.4	1.0	.3	.8	.2	.5
46.0	28.6	.4	.8	.3	.6	.2	.4
48.0	29.8	.3	.6	.2	.5	.1	.3
50.0	31.0	.2	.5	.2	.4	.1	.3
52.0	32.3	.2	.4	.1	.3	---	---
54.0	33.6	.1	.3	.1	.2	---	---
56.0	34.8	.1	.2	---	---	---	---

TABLE IV. - GRADEABILITY OF WATERMAN DAF

Vehicle speed		Amount of discharge, percent		
km/h	mph	0	40	80
		Grade vehicle can climb, percent		
0	0	0	0	0
2.0	1.2	12.9	15.9	18.1
4.0	2.5	17.4	22.9	25.1
6.0	3.7	23.0	27.6	28.9
8.0	5.0	26.5	28.6	28.9
10.0	6.2	31.0	24.7	23.1
12.0	7.5	23.9	17.8	15.7
14.0	8.7	14.3	13.1	10.5
16.0	9.9	9.6	9.4	7.1
18.0	11.2	6.8	6.2	4.9
20.0	12.4	5.2	4.5	3.8
22.0	13.7	4.4	4.0	3.1
24.0	14.9	3.7	3.5	2.7
26.0	16.2	3.2	3.0	2.5
28.0	17.4	2.8	2.8	2.5
30.0	18.6	3.0	2.8	2.8
32.0	19.9	3.1	3.3	3.7
34.0	21.1	3.4	4.1	4.4
36.0	22.4	4.5	4.9	4.5
38.0	23.6	5.3	5.2	4.1
40.0	24.9	5.6	4.9	3.6
42.0	26.1	5.5	4.4	3.2
44.0	27.4	4.4	3.6	2.5
46.0	28.6	3.6	2.9	2.0
48.0	29.8	2.9	2.5	1.5
50.0	31.1	2.4	1.9	1.2
52.0	32.3	1.9	1.4	----
54.0	33.6	1.3	.9	----
56.0	34.8	1.0	----	----

TABLE V. - ROAD ENERGY CONSUMPTION OF

WATERMAN DAF

Vehicle speed		Road energy consumed	
km/h	mph	MJ/km	kWh/mile
56.0	34.8	0.28	0.13
54.0	33.6	.28	.13
52.0	32.3	.29	.13
50.0	31.1	.28	.12
40.0	29.8	.28	.12
46.0	28.6	.29	.13
44.0	27.3	.29	.13
42.0	26.1	.30	.13
40.0	24.9	.30	.14
38.0	23.6	.29	.13
36.0	22.4	.29	.13
34.0	21.1	.32	.14
32.0	19.9	.32	.14
30.0	18.6	.31	.14
28.0	17.4	.29	.13
26.0	16.1	.27	.12
24.0	14.9	.27	.12
22.0	13.7	.26	.12
20.0	12.4	.25	.11
18.0	11.2	.24	.11
16.0	10.0	.23	.10
14.0	8.7	.21	.09
12.0	7.5	.19	.09
10.0	6.2	.19	.09

TABLE VI. - ROAD POWER REQUIREMENTS

OF WATERMAN DAF

Vehicle speed		Road power required	
km/h	mph	kW	hp
56.0	34.8	4.4	5.8
54.0	33.6	4.2	5.7
52.0	32.3	4.1	5.5
50.0	31.1	3.9	5.2
48.0	29.8	3.7	4.8
46.0	28.6	3.7	4.9
44.0	27.3	3.5	4.7
42.0	26.1	3.4	4.6
40.0	24.9	3.4	4.5
30.0	23.6	3.0	4.1
36.0	22.3	2.9	3.9
34.0	21.1	3.0	4.0
32.0	19.9	2.9	3.8
30.0	18.6	2.5	3.4
28.0	17.4	2.2	3.0
26.0	16.1	2.0	2.7
24.0	14.9	1.8	2.4
22.0	13.7	1.6	2.2
20.0	12.4	1.4	1.8
18.0	11.2	1.2	1.6
16.9	9.9	1.0	1.3
14.0	8.7	.8	1.1
12.0	7.5	.6	.9
10.0	6.2	.5	.7
8.0	5.0	.7	.9
6.0	3.7	.7	.9
4.0	2.5	.5	.7
2.0	1.2	.2	.3

TABLE VII. - INDICATED ENERGY CONSUMPTION

OF WATERMAN DAF

Vehicle speed or driving schedule		Indicated energy consumption	
km/h	mph	MJ/km	kWh/mile
40	25	1.00	0.45
		.96	.43
50	31	.83	.37
		.74	.33
Schedule B		0.89	0.40
		1.14	.51

TABLE VIII. - CHARGER EFFICIENCY TEST DATA FOR WATERMAN DAF

Time	Input power from kilowatt-hour meter, P_{in}, kW	Output power calculated from $V_{av} \times I_{av}$, P_{out}, kW	Energy efficiency, percent	Input power from watt-meter, P_{in}, kW	Output power from watt-meter P_{out}, kW	Power efficiency, percent
8:30 a.m.	2.29	1.87	81.0	2.36	2.07	87.7
9:45	1.82	1.55	84.7	1.93	1.79	93.0
10:00	2.99	2.03	81.5	2.55	2.33	91.4
11:15	2.21	1.80	81.4	2.36	2.10	89.0
12:30 p.m.	2.02	1.69	83.6	2.20	1.96	89.1
1:30	1.75	1.46	83.4	1.89	1.72	91.0
2:45	1.65	1.38	83.6	1.80	1.61	89.4
4:00	1.39	1.20	86.3	1.57	1.42	90.4
5:30	1.39	1.19	85.6	1.59	1.42	92.2
7:00	1.36	1.19	87.5	1.55	1.42	91.6
8:30	1.35	1.22	90.3	1.56	1.43	91.6

TABLE IX. - BATTERY SPECIFICATIONS FOR WATERMAN DAF

Length, m (in.)	0.26 (10.375)
Width, m (in.)	0.18 (7.188)
Height, m (in.)	0.28 (11.219)
Weight, kg (lbm):	
Dry	21.4 (47.2)
Wet	29.5 (65.1)
Electrolyte, liters (qt)	6.2 (6.6)
Number of life cycles (laboratory)	400 - 450
Fully charged specific gravity	1.280
Number of plates per cell	19

TABLE X. - CONSTANT-SPEED BATTERY AND MOTOR DATA FOR WATERMAN DAF

	40-km/h test (1/25/77)		50-km/h test (1/27/77)	
	First 25 percent of range	Last 25 percent of range	First 25 percent of range	Last 25 percent of range
Average motor current, $\bar{I}_M$, A	131	131	149	148
Average battery current, $\bar{I}_B$, A	131	131	149	148
Average motor voltage, $\bar{V}_M$, V	17.2	22.4	27.1	32.3
Average battery voltage, $\bar{V}_B$, V	44.6	39.4	45.5	42.7
Average motor power, $\bar{P}_M$, kW	5.4	4.6	6.6	6.1
Average battery power, $\bar{P}_B$, kW	5.4	4.6	6.6	6.1
Duty cycle, $\bar{D}_C$, percent	42	64	61	78
Total energy removed from battery, kWh	11.0		11.5	

TABLE XI. - MAXIMUM-ACCELERATION BATTERY PERFORMANCE FOR WATERMAN DAF

Time, s	Vehicle speed		Current, A	Voltage, V	Power, kW	Amount of discharge, percent
	km/h	mph				
10	26	16	152	46.6	7.1	0
20	39	24	374	42.5	15.9	0
50	55	34	200	45.1	9.0	0
10	26	15	152	45.1	6.9	40
20	35	22	376	41.5	15.6	40
50	51	32	207	44.4	9.2	40
10	24	15	139	43.3	6.0	80
20	34	21	330	39.1	12.9	80
50	51	32	189	42.1	8.0	80

TABLE XII. - BATTERY TEST DATA SUMMARY FOR WATERMAN DAF

Test date	Vehicle speed or driving schedule		Cell capacity, Ah		Battery overcharge, percent	Electrolyte specific gravity		Battery temperature, °C	
	km/h	mph	In	Out		Before test	After test	Before test	After test
1/25/77	40	25	202	146	38	1.290	1.117	14	24 - 33
1/26/77	40	25	192	142	35	1.290	1.117	12	24 - 32
1/27/77	50	31	160	133	20	1.294	1.127	12	25
2/2/77	50	31	146	121	21	1.291	1.148	10	16 - 22
2/9/77	50	31	141	127	11	1.295	1.148	14	30 - 32
3/13/77	Schedule B		---	122	--	1.296	1.145	19	27 - 33
3/18/77	Schedule B		150	---	--	1.291	1.145	8	23

Figure 1. - Side view of C. H. Waterman DAF sedan on Dynamic Science Test Track.

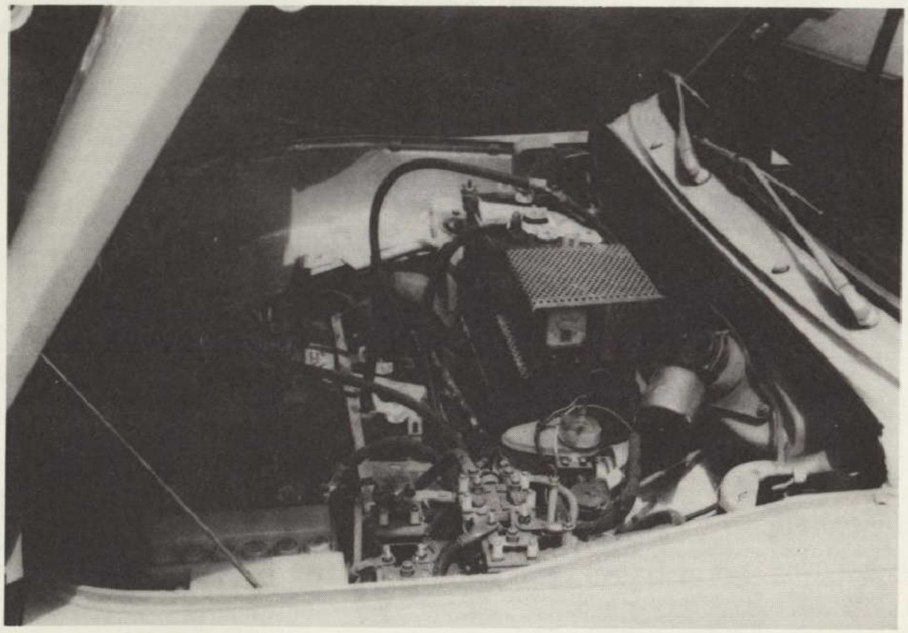


Figure 2. - Contactors and charger in Waterman DAF.

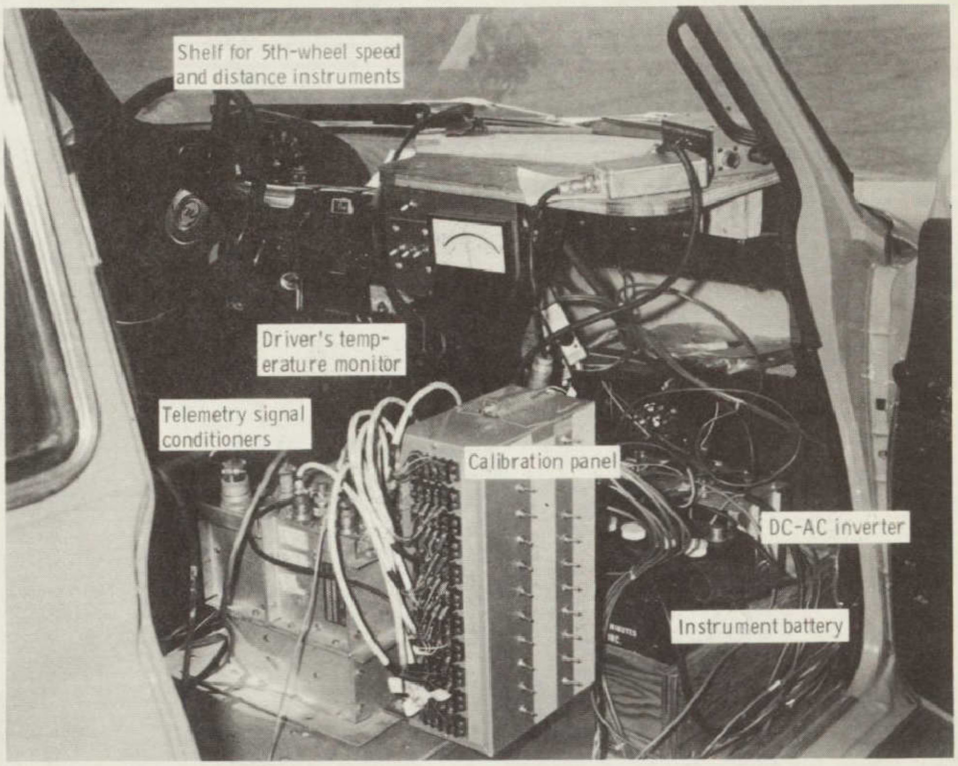


Figure 3. - Instrument system on passenger side of Waterman DAF.

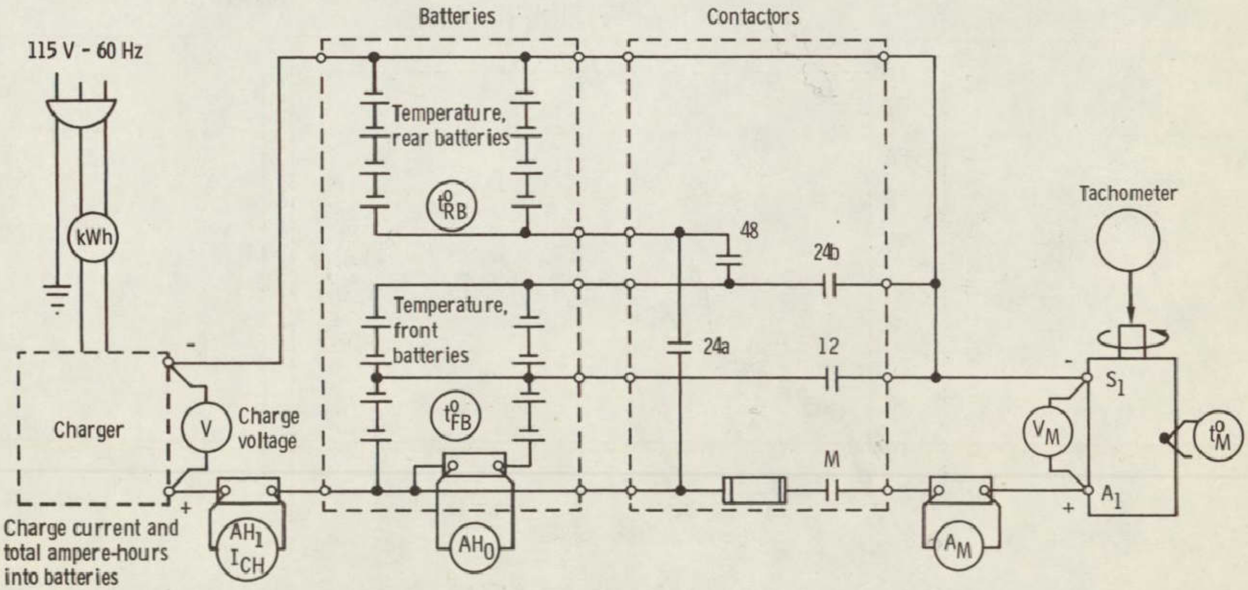
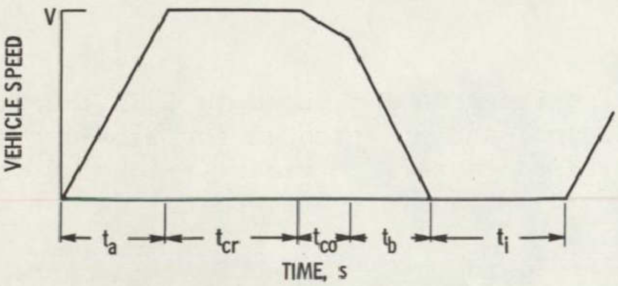


Figure 4. - Vehicle instrumentation for Waterman DAF.

ORIGINAL PAGE IS
OF POOR QUALITY



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 5. - SAE J227a driving cycle schedules.

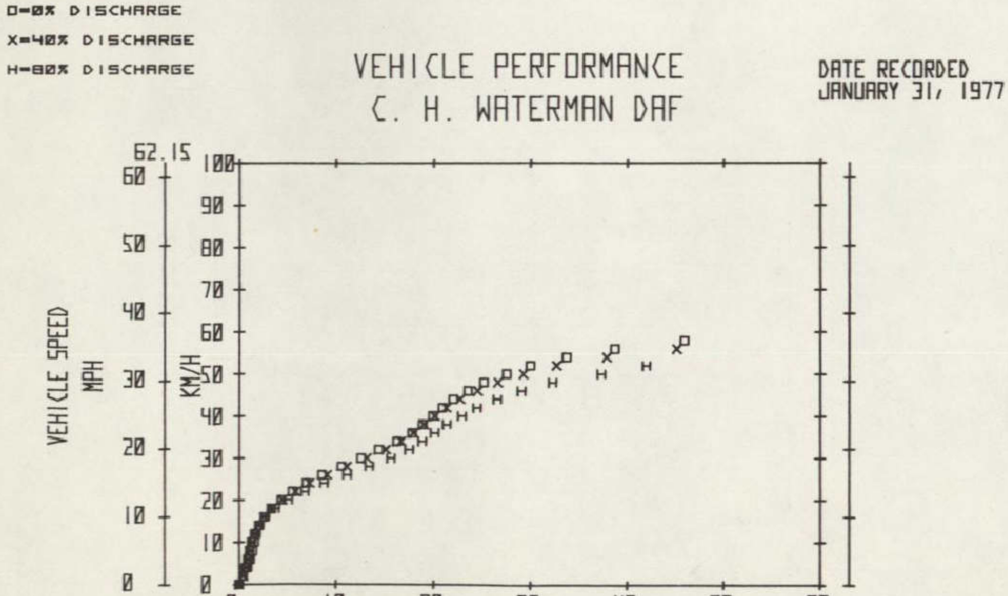


Figure 6. - Vehicle acceleration.

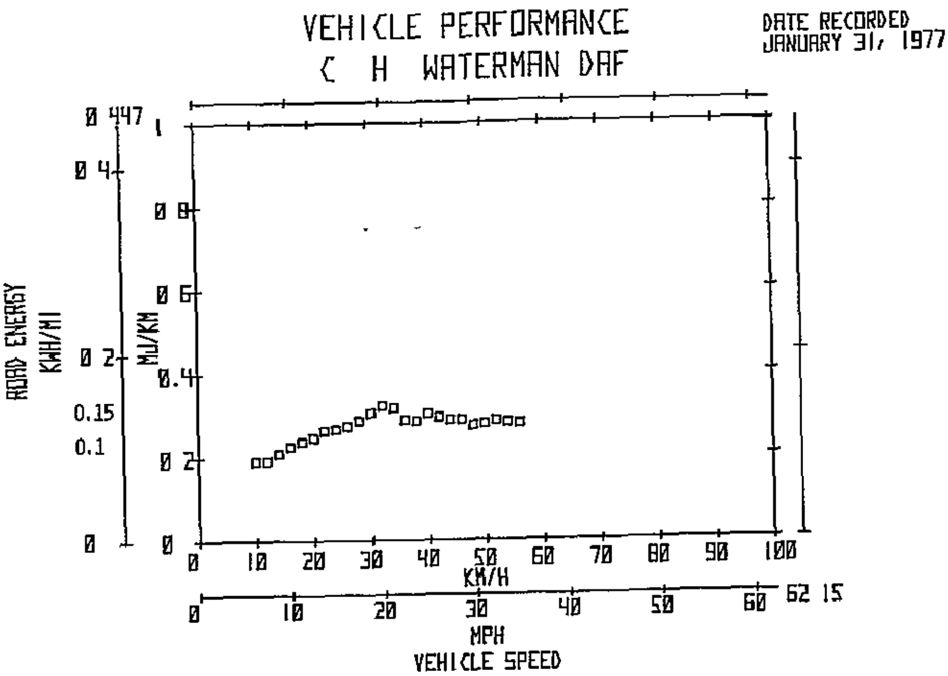


Figure 9. - Road energy as a function of speed

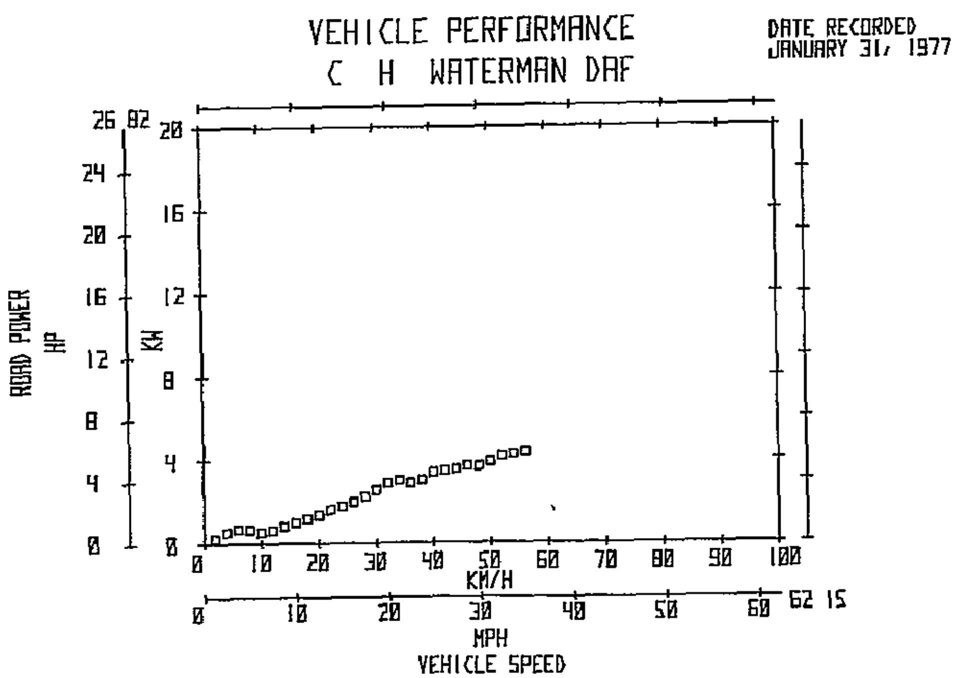


Figure 10 - Road power as a function of speed.

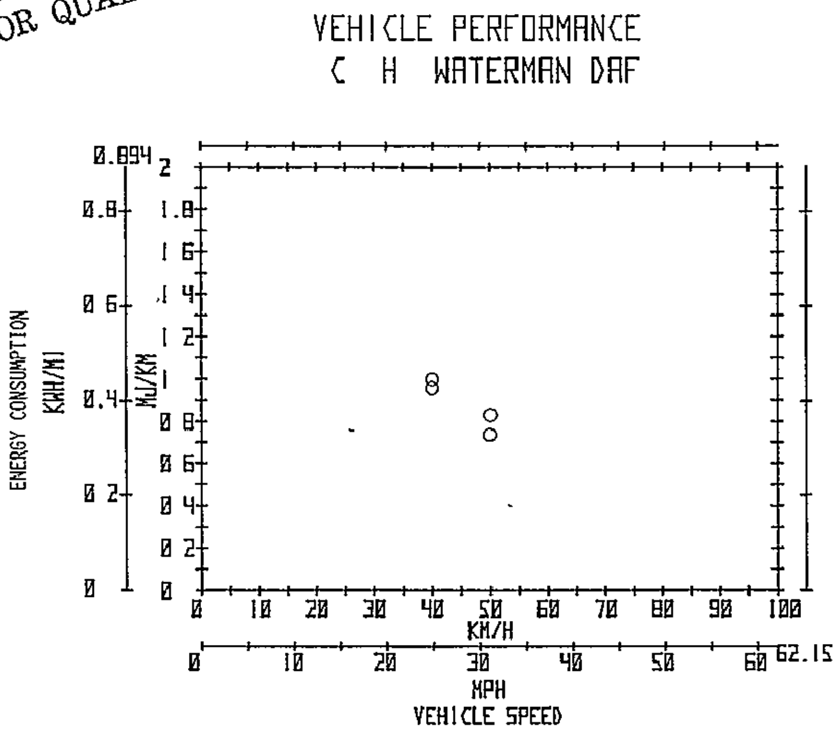


Figure 11 - Energy consumption as a function of speed.

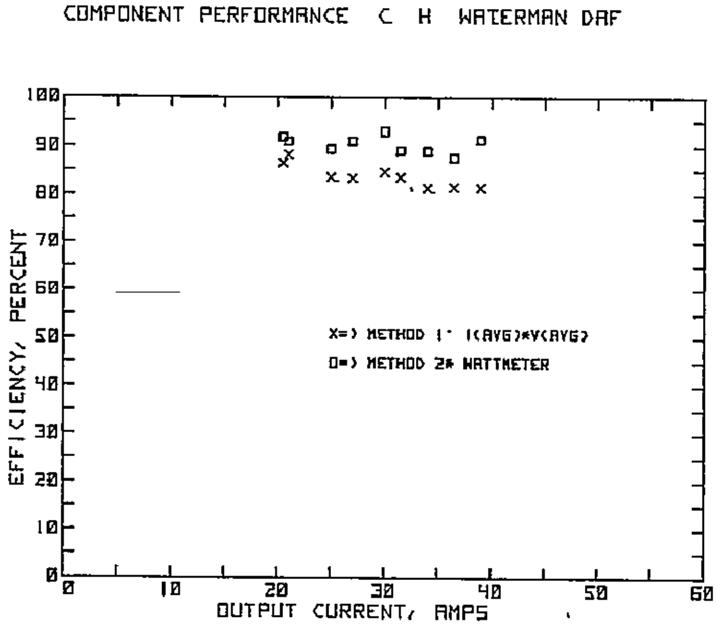


Figure 12 - Charger efficiency as a function of current

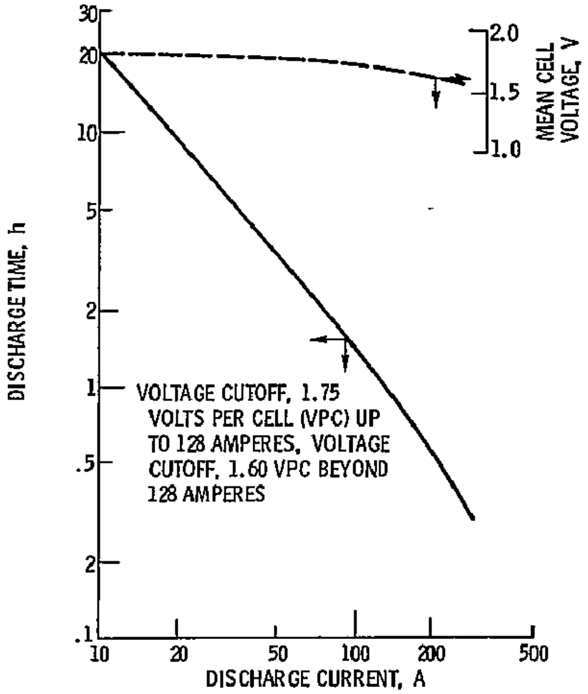


Figure 13. - Battery discharge characteristics for Waterman DAF

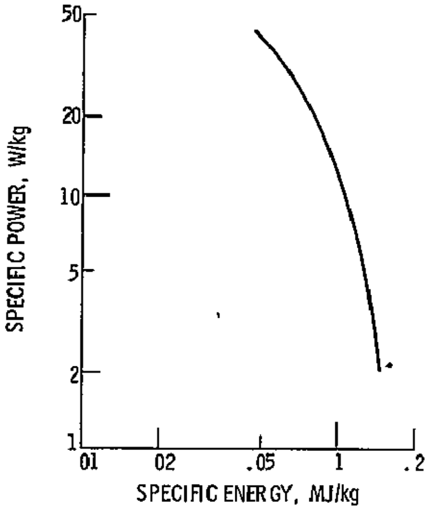
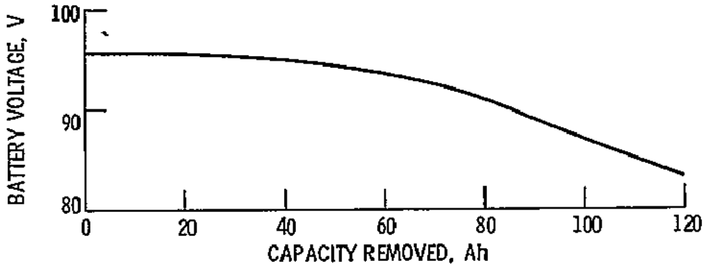
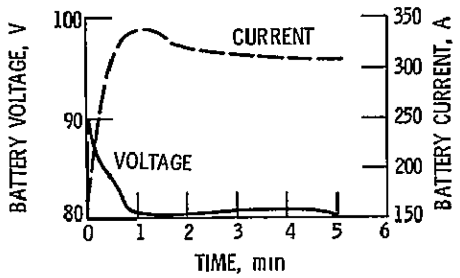


Figure 14 - Battery energy/power relationship for Waterman DAF.

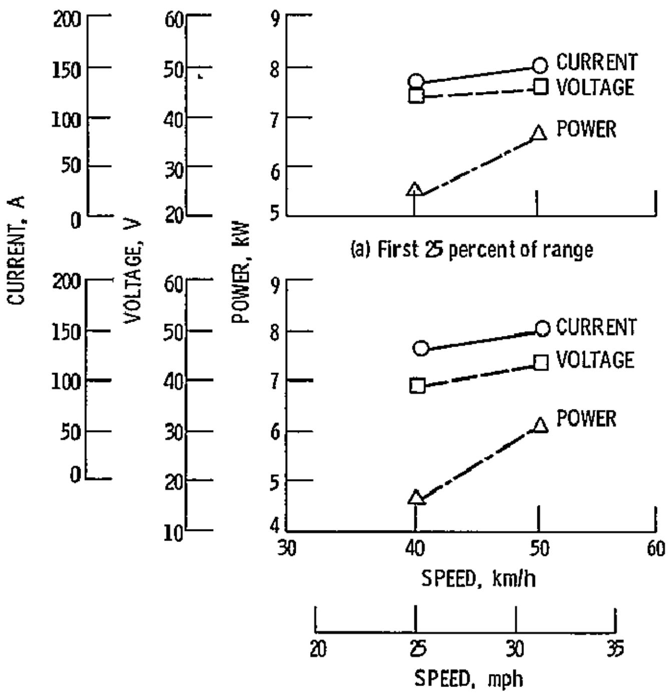


(a) Battery capacity check



(b) 300-Ampere battery terminal test

Figure 15 - Battery tests for Waterman DAF.



(b) Last 25 percent of range

Figure 16 - Constant-speed battery performance for Waterman DAF.

ORIGINAL PAGE IS OF POOR QUALITY

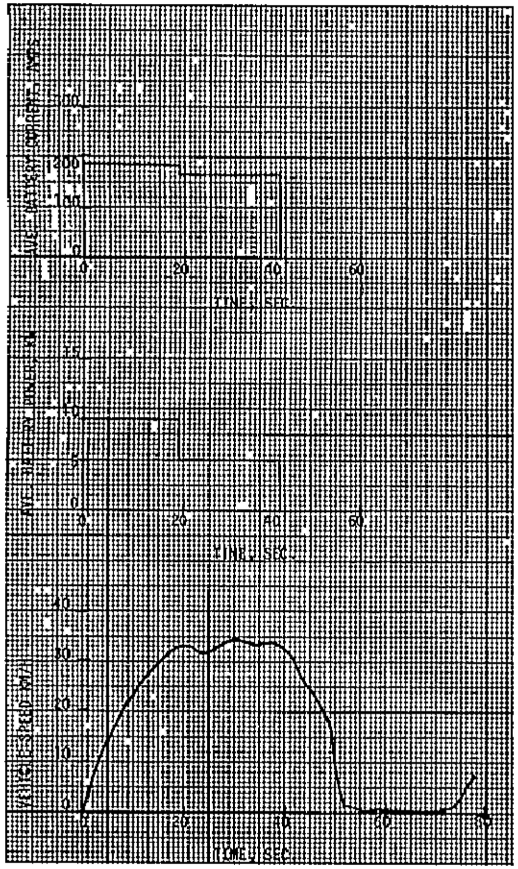


Figure 17. - Battery performance during third test cycle of schedule B test on March 13, 1977 - Waterman DAF.

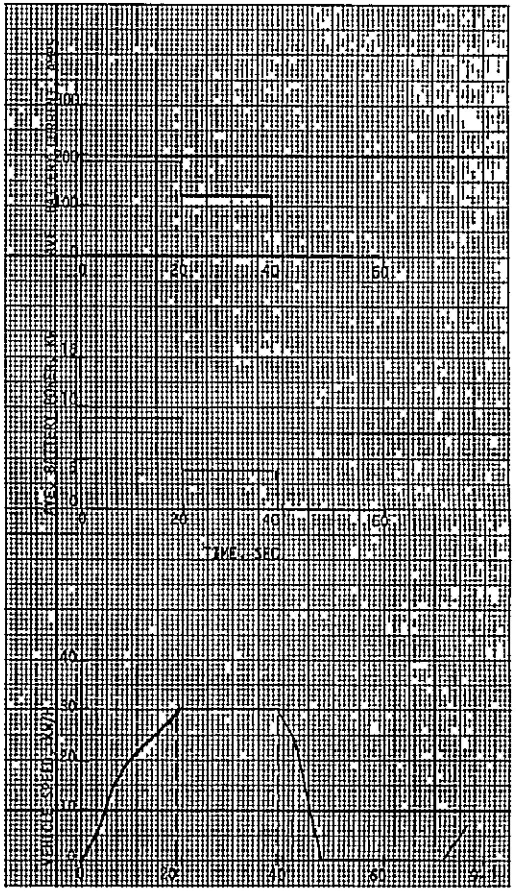
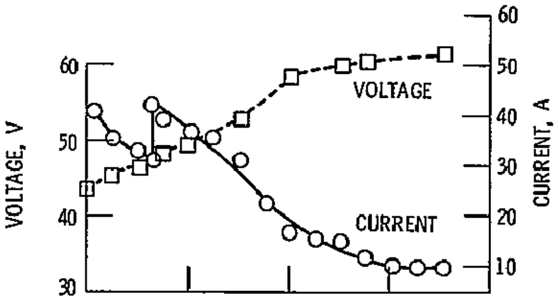
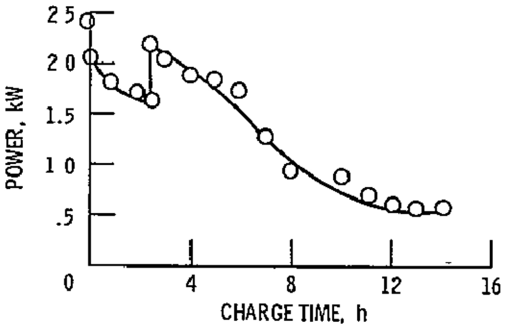


Figure 18. - Battery performance during 200th test cycle of schedule B test on March 13, 1977 - Waterman DAF.



(a) Charge time as function of voltage and current



(b) Charge time as function of power

Figure 19 - Battery charging profile (after 31-mph constant-speed test on Jan 27, 1977).

ORIGINAL PAGE IS
OF POOR QUALITY

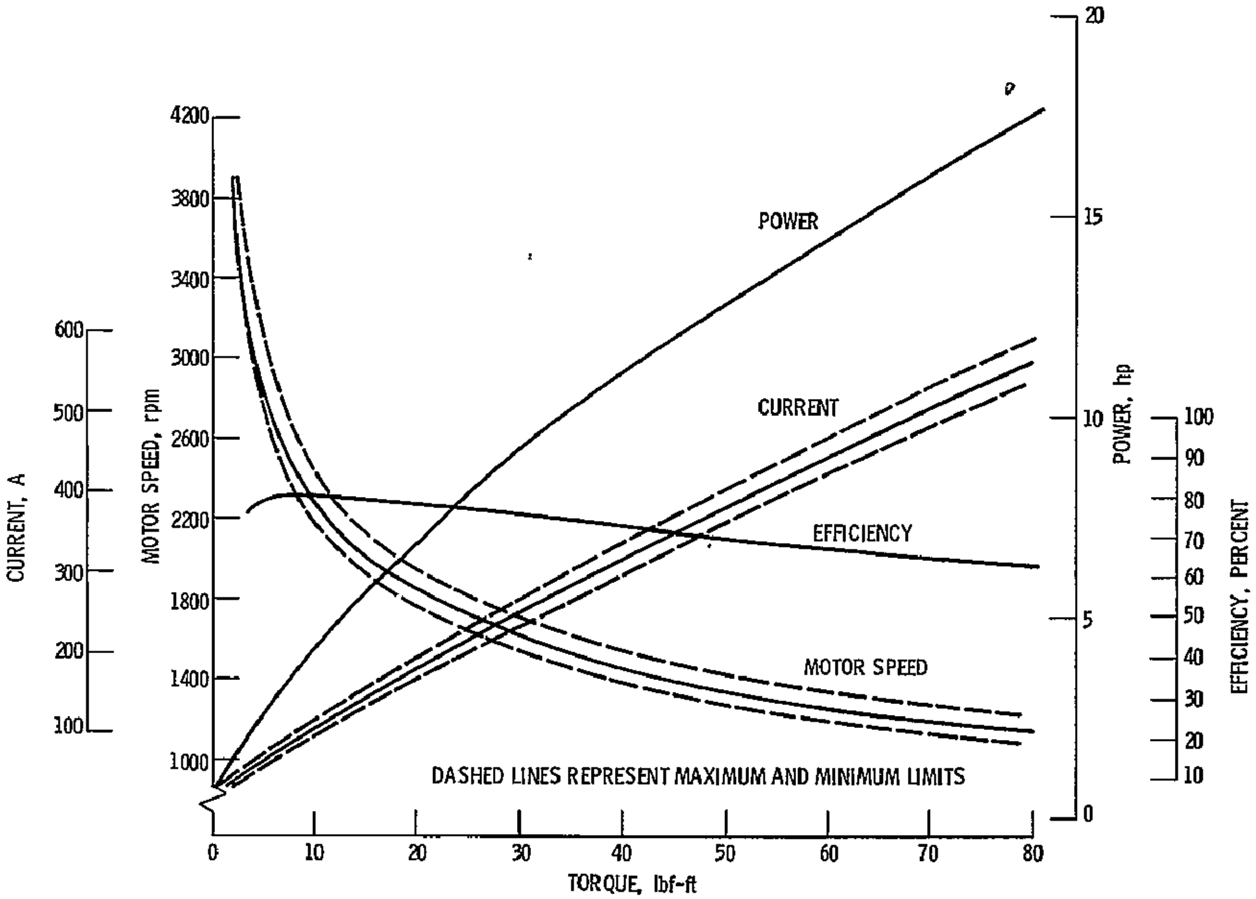


Figure 20. - Cold performance characteristics of Waterman DAF.

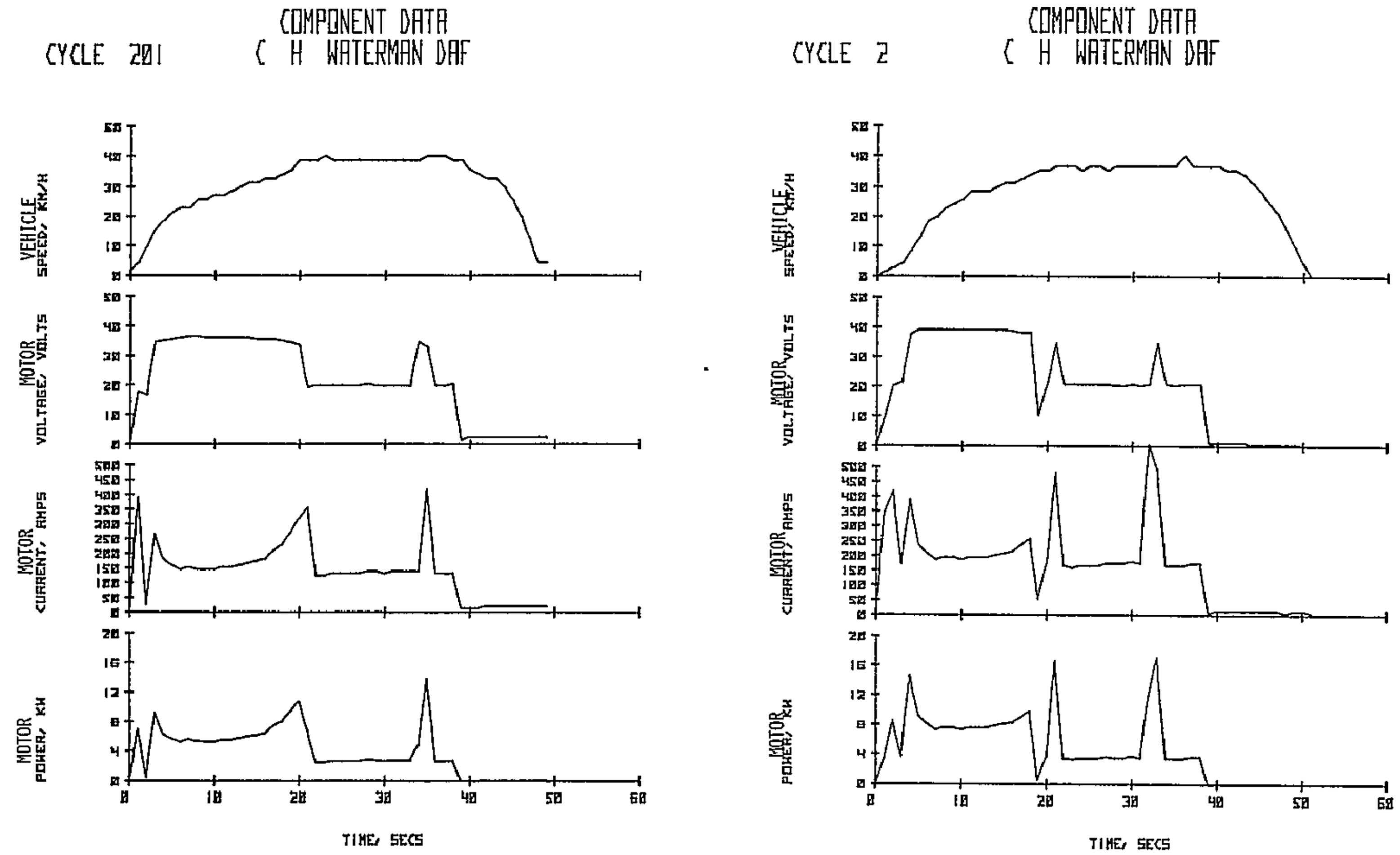


Figure 21 - Motor input as a function of time for schedule B cycle test

ORIGINAL PAGE IS OF POOR QUALITY

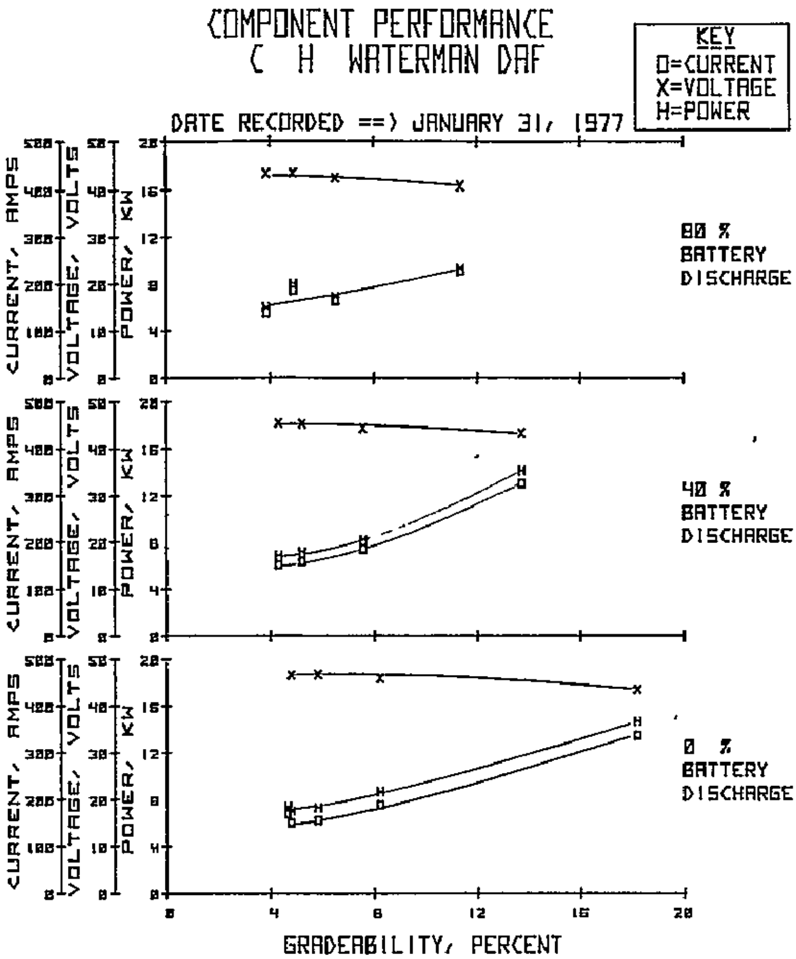


Figure 22 - Battery output as a function of gradeability.

APPENDIX A

VEHICLE SUMMARY DATA SHEET

1.0 Vehicle manufacturer C. H. Waterman Industries
Athol, Massachusetts

2.0 Vehicle DAF 46 conversion

3.0 Price and availability $6500; production on request

4.0 Vehicle weight and load

- 4.1 Curb weight, kg (lbm) 1225 (2700)
- 4.2 Gross vehicle weight, kg (lbm) 1365 (3010)
- 4.3 Cargo weight, kg (lbm) not applicable
- 4.4 Number of passengers 4 places
- 4.5 Payload, kg (lbm) 140 (310)

5.0 Vehicle size

- 5.1 Wheelbase, m (in.) 2.25 (88.5)
- 5.2 Length, m (ft) 3.58 (11.75)
- 5.3 Width, m (ft) 1.52 (5.0)
- 5.4 Height, m (in.)
- 5.5 Head room, m (in.) 0.98 (38.5)
- 5.6 Leg room, m (in.) 0.71 (28)
- 5.7 Frontal area, m^2 (ft^2)
- 5.8 Road clearance, m (in.)
- 5.9 Number of seats 3 (2 front (bucket), 1 rear (bench))

6.0 Auxiliaries and options

- 6.1 Lights (number, type, and function) 2 head, 2 park and tail, 2 brake, 2 front parking

6.2 Windshield wipers 2 on front windshield

6.3 Windshield washers yes

6.4 Defroster electric convection type on driver's side

6.5 Heater electric with fan

6.6 Radio optional

6.7 Fuel gage voltmeter with red-line

6.8 Amperemeter yes, with red-line

6.9 Tachometer no

6.10 Speedometer yes, in km/h

6.11 Odometer yes, in km

6.12 Right- or left-hand drive left

6.13 Transmission variomatic

6.14 Regenerative braking no

6.15 Mirrors rear view

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 golf car (EV-106); ESB, Inc.

7.1.2 Number of modules 16

7.1.3 Number of cells 48

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

7.1.5 Capacity, Ah 132.5 (106 min at 75 A)

7.1.6 Size of each battery, m (in.) height, 0.248 (9.75); width, 0.178 (7); length, 0.260 (10.25)

7.1.7 Weight, kg (lbm) 472 (1040)

7.1.8 History (age, number of cycles, etc.) not available

7.2 Auxiliary battery

7.2.1 Type and manufacturer lead-acid SLI; VARTA Batterie AG

7.2.2 Number of cells 6

7.2.3 Operating voltage, V 12

7.2.4 Capacity, Ah 36

7.2.5 Size, m (in.) height, 0.178 (7); width, 0.165 (6.5)

7.2.6 Weight, kg (lbm) 20.4 (45)

8.0 Controller

8.1 Type and manufacturer contactor; C. H. Waterman Industries

8.2 Voltage rating, V not available

8.3 Current rating, A not available

8.4 Size, m (in.) height, 0.127 (5); width, 0.203 (8); length, 0.229 (9)

8.5 Weight, kg (lbm) 9 (20) est.

9.0 Propulsion motor

9.1 Type and manufacturer DC series; Prestolite Electrical Div., Eltra Corp.

9.2 Insulation class H

9.3 Voltage rating, V 36

9.4 Current rating, A 250, 1-h rating

9.5 Horsepower (rated), kW (hp) 6.7 (9), 1-h rating

9.6 Size, m (in.) diam, 0.190 (7.5); length, 0.356 (14)

9.7 Weight, kg (lbm) 45.4 (100)

9.8 Speed (rated), rpm 1630 (maximum unknown)

10.0 Battery charger

10.1 Type and manufacturer full-wave, center-tapped; C. H. Waterman Industries

10.2 On- or off-board type on board

10.3 Input voltage required, V 120 (AC)

10.4 Peak current demand, A 20

10.5 Recharge time, h 10

10.6 Size, m (in.) height, 0.203 (8); width, 0.178 (7); length, 0.279 (11)

10.7 Weight, kg (lbm) 22.7 (50)

10.8 Automatic turnoff feature yes, timer

11.0 Body

11.1 Manufacturer and type DAF 46 sedan

11.2 Materials steel

11.3 Number of doors and type 2

11.4 Number of windows and type 6; glass

11.5 Number of seats and type 2 bucket (front); 1 bench (rear)

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

11.7 Cargo space dimensions, m (ft)

12 0 Chassis

12.1 Frame

12.1.1 Type and manufacturer welded construction; DAF

12.1.2 Materials steel

12.1.3 Modifications battery-retaining members added

12.2 Springs and shocks

12.2.1 Type and manufacturer rear, leaf; front, coil

12.2.2 Modifications none

12 3 Axles

12 3.1 Manufacturer DAF

12.3.2 Front independent

12.3 3 Rear De Dion

12.4 Transmission

12 4.1 Type and manufacturer Variable-sheave pulley, DAF

12.4.2 Gear ratios infinitely variable from 3.6 to 14.22

12.4.3 Driveline ratio 3.6, in overdrive

12.5 Steering

12.5.1 Type and manufacturer rack and pinion

12.5.2 Turning ratio

12 5.3 Turning diameter, m (ft) 10.1 (33)

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 135SR14ZX

12.7.3 Pressure, kPa (psi):

Front 193 (28)

Rear 193 (28)

12.7.4 Rolling radius, m (in.) 0.280 (11.02)

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) 64.4 (40)

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

13.3 Tested at cruise speed, km/h (mph) 49.9 (31); 40.2 (25)

APPENDIX B

DATA ACQUISITION

Data acquired from the test vehicle are conditioned onboard the vehicle and transmitted to the Data Acquisition Center where they are demodulated and recorded on magnetic tape (fig. B-1).

The following paragraphs provide a detailed description of system components. Instrumentation calibration procedures and test procedures relative to the data acquisition system are also described.

Signal Conditioning Equipment

The signal conditioning equipment has a modular or building-block configuration. The basic building block is the remote signal conditioning module (RSCM), which consists of all the necessary functions required to take the basic transducer information and store it on magnetic tape. Each RSCM handles 14 data channels.

Internally, the RSCM consists of all the necessary components required to signal condition, modulate onto Inter-Range Instrumentation Group (IRIG) constant-bandwidth frequency-modulated (FM) channels, and transmit a transducer output signal to a remote tape recorder. Figure B-2 is the system diagram defining this RSCM.

The signal conditioning amplifiers in the front end of the RSCM provide suitable gain and balance to normalize all transducer outputs into common formats and to drive the voltage-controlled oscillators (VCO's). Each amplifier has a built-in, isolated bridge power supply regulated at 5.0 volts DC that negates loading effects from other transducers and changes in output due to supply battery variations. This power supply is used either alone, divided down by 0.1-percent metal film resistors, or in series with other supplies to provide a highly accurate and stable voltage insertion calibration of the entire system, channel by channel.

The VCO's convert analog voltages to a frequency-modulated unbalanced signal. The center frequencies of the VCO's are set at values defined by IRIG 106-71 for constant-bandwidth channels (table B-1). The ±2.5-volt outputs from the amplifier provide ±100-percent deviation of the VCO's. Using a mix of A and B channels provides an optimum combination of data frequency response, resolution, percentage of deviation, and channel density in each multiplex.

The system is designed to provide 1000-hertz data channel bandwidth on all A channels and 2000-hertz channel bandwidth on all B channels. The 14 VCO outputs are mixed onto a common bus which provides the output signal to be recorded. An external 28-volt battery is used to power the RSCM.

Each RSCM weighs under 9 kilograms (20 lbm) and covers approximately 390 square centimeters (60 in^2) of floor space. All input and output connections and final adjustments are accessible from the top of the module.

System Accuracy

Table B-2 represents the system errors for the data acquisition system. The values are taken from the component specifications. As there are several information conversions through the system, there was an attempt to translate the specifications into a "common error domain." Each device in the system has a set of parameters that represent its performance in a particular region of the multidimensional space (e.g., an accelerometer converts an acceleration into a voltage (actually an energy conversion) with some nonlinearity of information conversion). There is a conversion from analog voltage to frequency with a corresponding nonlinearity in the VCO. The tape recorder has to handle the information mechanically with high accuracy because a change in tape speed represents a change in frequency which, in turn, represents a change in the original analog voltage.

Tape Recorders

The tape recorder has 14 IRIG-compatible channels, with the recording channels individually controlled so that multiple recording passes may be made on the same tape. Capstan speed accuracy of 0.01 percent is obtained by use of a tape speed compensator system while flutter is held to 0.22 percent. Time base and dynamic skew are 0.5 and 25 microseconds, respectively.

TABLE B-1. - CONSTANT-BANDWIDTH CHANNELS

IN EACH REMOTE SIGNAL-CONDITIONING

MODULE FOR WATERMAN DAF

IRIG constant-bandwidth channel	Center frequency, kHz	Deviation, kHz
1A	16	+2
2A	24	
3A	32	
4A	40	
5A	48	
6A	56	
7A	64	
8A	72	
9A	80	
11B	96	+4
13B	112	
15B	128	
17B	144	
19B	160	

TABLE B-2. - DIRECT-CURRENT AMPLITUDE ACCURACY

Transducer	Parameter	Accuracy, percent
DC voltage	Tolerance	±0.4
Calibration resistors	Tolerance	±.1
Amplifier	Nonlinearity	±.5
Voltage-controlled oscillator	Nonlinearity	±.25
Recorder	Speed inaccuracy	±.01
Data demodulator	Nonlinearity	±.1

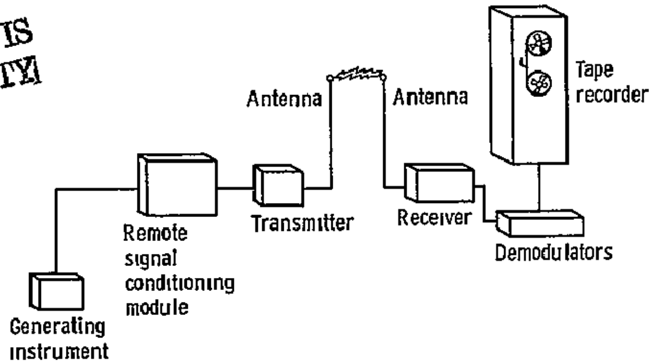


Figure B-1 - Data acquisition system schematic.

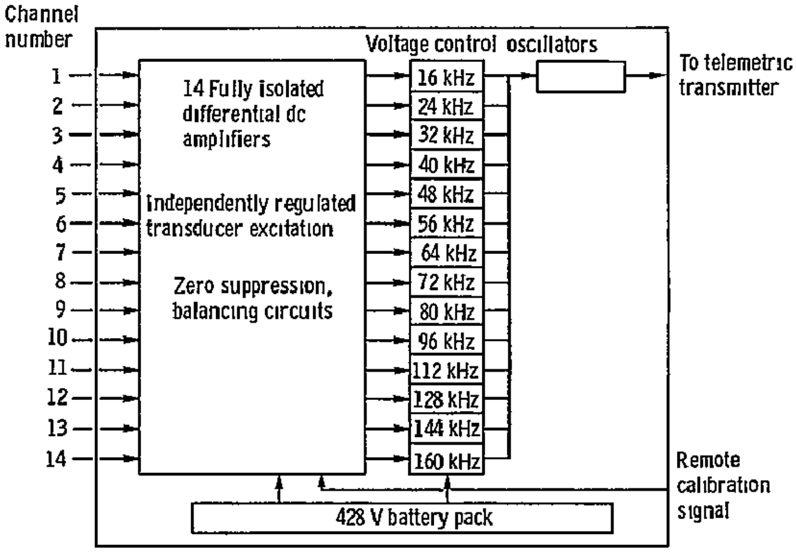


Figure B-2 - Remote signal conditioning module diagram

APPENDIX C

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 C-1. Average grade is 0.66 percent on the northern straight section and 0.76 percent on the 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 track. Both 20- and 30-percent grades are available for parking brake tests.

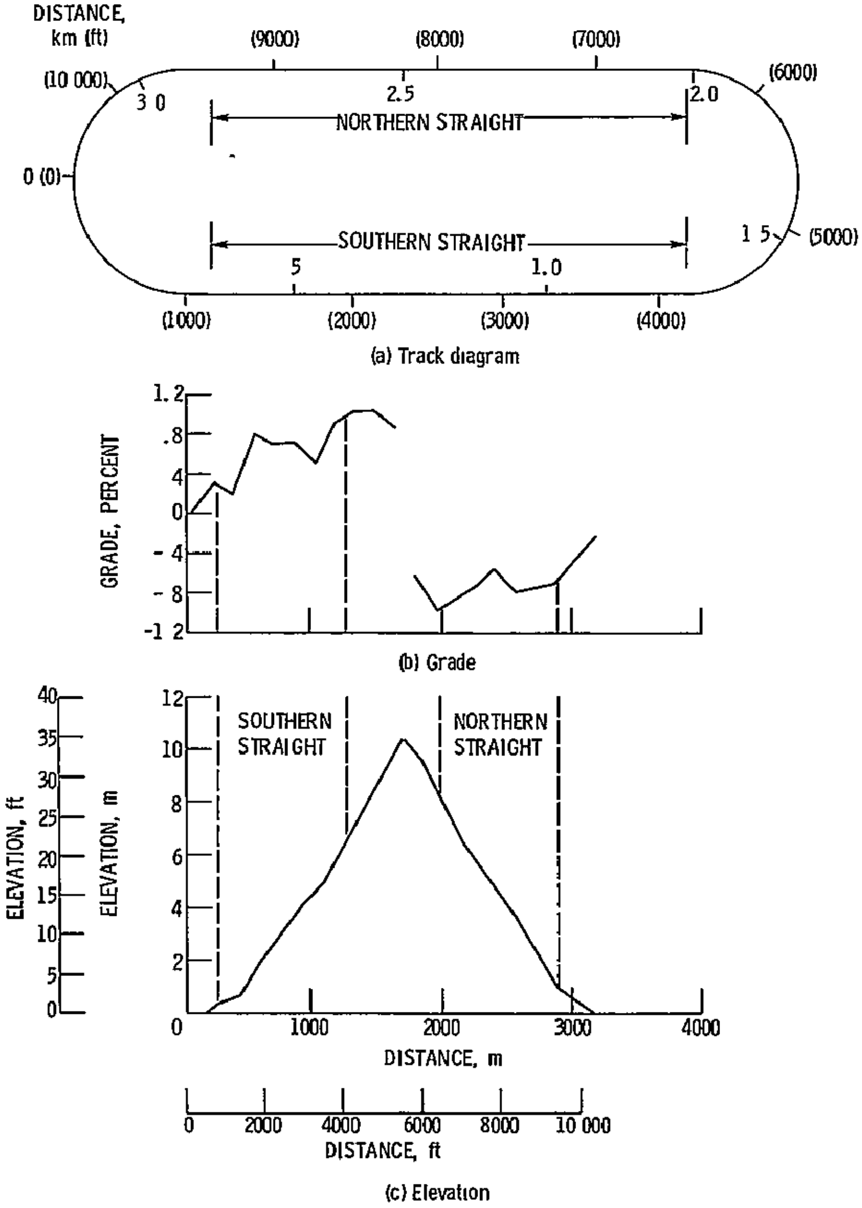


Figure C-1. - Characteristics of Dynamic Science Test Track, Phoenix, Arizona.

ORIGINAL PAGE IS OF POOR QUALITY

APPENDIX D

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 D-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 D-2.

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

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

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 D-1. - Vehicle preparation check sheet

ORIGINAL PAGE IS
OF POOR QUALITY

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

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 D-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 D-2. - Concluded

ORIGINAL PAGE IS
OF POOR QUALITY

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 D-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 D-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 D-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 D-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 D-7 - Engineer's data sheet

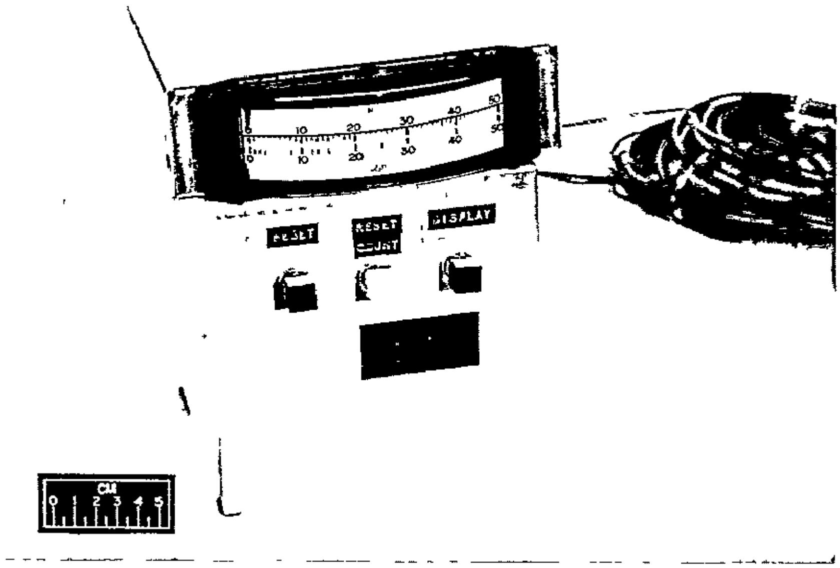


Figure D-8. - Cycle timer

ORIGINAL PAGE IS
OF POOR QUALITY

APPENDIX E

ELECTRIC AND HYBRID VEHICLE TEST AND EVALUATION PROCEDURE

This procedure for testing electric and hybrid vehicles was prepared by the ERDA Division of Transportation Energy Conservation to standardize the procedures for testing vehicles. It was followed by NASA in conducting the tests and in evaluating the performance of the vehicle described in this report.

CONTENTS

ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
ELECTRIC AND HYBRID VEHICLE TEST AND EVALUATION PROCEDURE
(ERDA-EHV-TEP)
July 1977

1.0 Objective and Purpose

1.1 Objective and Purpose of the Project

The test project objective is to continually evaluate representative state-of-the-art electric and hybrid vehicles, subsystems and components. The test results should:

- Verify, correct and add to the vehicle manufacturer's data sheets
- Provide a common basis for cross comparison of vehicle:
  - design specifications
  - purchase specifications
  - technical papers
  - engineering decisions

In addition, the analyzed data and reports will be used for ERDA research and development program planning toward acceleration of component and vehicle technology.

1.2 Objective and Purpose of the Test Procedure and Data

The test procedure objective is to provide a standard approach for testing which will allow performance characteristics of vehicles and in situ components to be measured on a common basis for cross comparison. Vehicle comparison is derived from the gross vehicle performance characteristics reduced to unitized form, such as performance per cycle, per ton mile or seat mile. Powertrain performance projections are derived from the gross vehicle performance and the associated component and subsystem efficiency results. The total results measure the vehicle state-of-the-art and develop a component, powertrain and subsystem information base from which to plan electric and hybrid vehicle research and development programs.

2.0 Test Procedure

This ERDA test procedure uses and references the Society of Automotive Engineers Recommended Practice, Electric Vehicle Test Procedure (SAE J227a) as a base to build a more detailed test procedure. The ERDA Electric and Hybrid Vehicle Test and Evaluation Procedure (ERDA-EHV-TEP) includes instrumentation and procedures to collect powertrain, powertrain component and braking data. The SAE J227a concentrates on the attributes of the gross vehicle system reserving subsystem and component testing to separate procedures.

2.1 Scope and Itemized Tests

The objective, purpose and scope of this test procedure is detailed in Section 1.2 of this procedure. The specific tests covered by this document are:

- Range at Steady Speed (Section 2.8.1)
- Range on a Driving Cycle (Section 2.8.2)
- Acceleration on a Level Road (Section 2.8.3)
- Gradeability Limit (Section 2.8.4)
- Gradeability at Speed (Section 2.8.5)
- Road Energy Consumption (Section 2.8.6)
- Vehicle Energy Economy (Section 2.8.7)
- Braking (Section 2.8.8)
- Handling (Section 2.8.9)

2.2 Terminology

2.2.1 Curb Weight. - The total weight of the vehicle including batteries, lubricants and other expendable supplies, but excluding the driver, passengers and other payloads.

2.2.2 Drive Line Ratio. - The motor shaft rpm divided by the rpm of the traction wheels of the vehicle.

2.2.3 Gradeability. - The maximum percent grade which the vehicle can traverse at a specified speed. The gradeability limit is the grade upon which the vehicle can just move forward.

2.2.4 Initial State of Charge (of Battery). - The amount of energy stored in the battery. When practical, the initial state of charge should be expressed as a percent of the capacity obtainable from a fully charged battery when discharged at a rate equivalent to the vehicle maximum cruise speed discharge rate.

2.2.5 Projected Frontal Area. - The total frontal area of the vehicle obtained by projecting its image on a vertical plane normal to its direction of travel.

2.2.6 Tractive Force. - The force available from the driving wheels at the driving wheel ground interface.

2.2.7 Tire Rolling Radius. - The effective radius of a tire when it is deformed by the weight of the vehicle ballasted to its rated gross vehicle weight (SAE J670c).

2.2.8 Maximum Cruise Speed. - The highest vehicle speed sustainable for at least 1 hour under specified environmental road test conditions starting with a fully charged battery, or such other maximum cruise speed as may be recommended by the vehicle manufacturer.

2.2.9 Powertrain. - The energy storage components (batteries, etc.), power conditioning controls and propulsion unit (electric motor, etc.)

2.2.10 Gross Vehicle Weight. - The total weight of the vehicle, including batteries, lubricants, expendable supplies, driver, passengers and other payload.

2.2.11 Vehicle Test Weight. - The vehicle test weight is the vehicle weight during testing, including batteries, lubricants, expendable supplies, driver, passengers and other payload.

2.3 Vehicle Condition

Upon receipt of a vehicle, it is to be inspected for visible damage. Damage is to be photographed and reported immediately to the shipping company, to the manufacturer and to the ERDA program manager. If the vehicle appears to be in good condition, it is to be driven by test personnel for familiarization with its handling and performance characteristics. Wiring diagrams are to be studied and the propulsion system inspected to determine the appropriate locations for test instrument and sensor locations.

2.3.1 The vehicle shall be tested in its normal configuration with all normal appendages, mirrors, bumpers, hubcaps, etc. The vehicle shall be tested at the manufacturer's rated gross vehicle weight.

2.3.2 The front wheel alignment shall be checked to ensure that it is set to the manufacturer's specifications.

2.3.3 The manufacturer's recommended tires shall be used. Tire pressures shall equal the vehicle manufacturer's recommended values or pressures, except that tire pressures shall not exceed pressures recommended by the Tire and Rim Association. Tire tread shall not be worn to the point where the tread wear indicators are exposed.

2.3.4 Normal manufacturer's recommended lubricants shall be employed.

2.3.5 Vehicle checks preliminary to test:

2.3.5.1 Ability to fully charge and equalize battery cells.

2.3.5.2 Draw the maximum vehicle manufacturer allowed load current but not greater than 300 amperes from the fully charged batteries into a load at battery terminals for 5 minutes while monitoring battery terminal interconnection temperatures. Measurements can be made with a hand-held temperature monitor for the last 2 minutes or with temperature sensitive labels. If any terminal or interconnect should exceed 60 degrees Celsius above ambient, or if any terminal temperature rises rapidly above the average of the others, the test shall be terminated, the terminal checked and repaired.

2.3.5.3 Tire pressure for possible air leaks.

2.3.5.4 All lights for proper function.

2.3.5.5 All brakes for drag, air in hydraulic lines, etc.

2.3.5.6 All safety equipment for proper function.

2.3.5.7 Weight of the vehicle without driver and test equipment and with the fifth wheel off the scale but down.

2.3.5.8 Weight of the vehicle with the driver, all the test equipment and ballast weight* to meet the manufacturer's payload specifications. The fifth wheel shall be up so it is included as part of the test equipment weight.

2.3.5.9 Calibration of the instrumentation package and recorder(s) installed.

2.3.5.10 Operation of the vehicle on short sample road tests simulating all probable test conditions. Check out all channels of the instrumentation package and recorder(s).

2.3.6 The vehicle shall be stored at an ambient temperature for sufficient time to allow the power train and chassis to reach the temperature range of (5 to 32 degrees Celsius) 40 to 90 degrees Fahrenheit. Battery electrolyte temperature must be below 90°F when the tests begin.

---

* GVW (test weight) may vary ± 2 percent from manufacturer's specifications. Distribution of the test load shall be such that actual vehicle weight distribution (percent front versus percent rear) is also within 2 percent of the manufacturer's specifications.

2.3.7 The vehicle track tests will be terminated when a vehicle failure occurs that requires either (1) more than 24 hours to repair or (2) the repair results in modifications to the vehicle that significantly change the performance of the vehicle.

2.4 Battery Condition

2.4.1 If batteries are new or have been subject to extended storage, the batteries shall be cycled per the manufacturer's recommendation before starting tests.

2.4.2 Full charge is to be established using manufacturer's recommended charging procedure and equipment.

2.4.3 For tests requiring an X percent discharged battery at the start (for example, gradeability tests), the required initial state-of-charge will be established as follows: A Range at Steady State test shall be performed at recommended maximum cruise speed, and the end-point of range determined as defined in Section 2.8.1.2.2 and the amp hours taken from the battery measured. To achieve X percent discharge of a fully charged battery, the battery will be discharged by driving the vehicle at recommended maximum cruise speed or by discharging the battery through a load at an equivalent constant power until X percent of the amp hours as determined above are removed from battery. Tests conducted with the battery partially discharged at the start must be initiated no longer than 10 minutes after the desired initial state-of-discharge is reached.

2.4.4 For tests in which the effects of battery initial state-of-charge are to be investigated, tests should be conducted with the propulsion batteries at 0 percent, 40 percent, and 80 percent discharged.

2.4.5 Capacity and Quality Verification - The battery shall be discharged at the 3-hour or other manufacturer's published rate (to 1.7 volts/cell specific gravity 1.160 + .01 for lead acid). The capacity shall be within 20 percent of the manufacturer's capacity at the published rate to pass this test. A second cycle shall be run to verify the battery's quality.

2.4.6 Before each vehicle test cycle (unless otherwise specified), lead/acid batteries shall be fully charged and equalized. If the specific gravity of any cell is 10 points below the battery manufacturer's specification for full charge, the cell shall be checked and replaced if necessary. (Equalization is normally determined by measuring the electrolyte specific gravity of all cells each hour during the finishing trickle charge. When the readings stay essentially constant, the batteries are equalized.)

2.5 Environmental Conditions

2.5.1 Ambient temperature during road testing shall be in the range of 5 degrees to 32 degrees C (40 degrees to 90 degrees F), except short tests may be conducted wherein the average temperature of the vehicle chassis and powertrain does not exceed the prescribed temperature limits.

2.5.2 Road tests are to be performed on a road which is level to within ± 1 percent and having a hard, dry surface. Tests shall be run in opposite directions when they are performed on a road test route. The direction of travel need not be reversed when operating on a closed test track.

2.5.3 The recorded wind speed at the test site during test shall not exceed 16 km/h (10 mph), gusts shall not exceed 24 km/h (15 mph).

2.6 Instrumentation

2.6.1 Test Instrumentation. - This section provides a list of instrumentation required to perform the tests specified in this procedure. The overall error in recording or indicating instruments shall be no worse than ± 2 percent of the maximum value of the variable to be measured (not including reading errors). Periodic calibration shall be performed and documented to insure compliance with this requirement.

2.6.2 General Instrumentation. - The following classes of instruments are required for the purpose of tests outlined in this procedure:

- A.C. watt-hour meter or watt-time recorder
- D.C. watt-hour meter or watt-time recorder
- Distance versus time recorder
- Tire pressure gauge
- Periodic ambient temperature measurements during tests
- D.C. watt meter (calculation is option)
- Battery temperature indicator
- Battery voltage versus time
- Battery current versus time
- Motor shaft speed versus time or vehicle speed
- Motor input current versus time
- Motor input voltage versus time
- Stopwatch
- A suitable multichannel recording system
- A fifth wheel
- Humphrey instrumentation package or equivalent for handling tests in Section 2.8.9
- Periodic wind speed and direction measurement during tests
- Means for determining grades of test route segments

2.7 Data to be Recorded

2.7.1 General

2.7.1.1 Manufacturer's specification sheet data.

2.7.1.2 Vehicle identification.

2.7.1.3 Overall maximum dimension (including projected frontal area).

2.7.1.4 Weight· curb weight and test weight to within ± 2 percent.

2.7.1.5 Battery:

- Manufacturer

- Type and normal rating at specified discharge rate

- Previous history of the battery, including chronological age, number and nature of charge-discharge cycles, serial numbers

- State of initial charge using the definition of percent charge presented in Sections 2.4.3 and 2.4.4. Where meaningful, other parameters such as open circuit voltage, electrolyte specific gravity, etc., shall also be started.

- Watt-hours consumed during test

- Power required during test

- Temperature at the start and the end of the test (either within the electrolyte or at the cell terminal, as appropriate)

- Recharge energy

- Recharge amp-hours

- Recharge time

2.7.1.6 Motor type and rating.

2.7.1.7 Overall drive train ratio(s) available, and those used during test, plus vehicle manufacturer's recommended shift points of manual transmission.

2.7.1.8 Tires: manufacturer, design, size, rolling radius measured at GVW, and the pressure at the start and the end of the test.

2.7.1.9. Power required for individual accessories, either measured or as specified by vehicle manufacturer, and times when each accessory was on during the test.

2.7.1.10 Environmental conditions:

- Range of the ambient temperature during test
- Range of the wind velocities during test
- Range of the wind direction during test
- Presence of any precipitation during test
- Mean test site altitude relative to sea level

2.7.1.11 Running surface.

2.7.1.12 Description of test route: road class, road surface type and condition (table 9 of SAE J688), and the lengths and grades of the test route.

2.7.1.13 Date and the starting and ending times of test.

2.7.1.14 List of all instrumentation used in the test (manufacturer, model number, serial number) and their last calibration date.

2.7.1.15 Any deviation from the test procedure and the reason for the deviation.

2.7.2 Road Tests

2.7.2.1 Range data shall be recorded and averaged for tests in opposite directions when tests are run on a road test route. The data reported shall be the average of at least two test runs, one in each direction. The range of the test results and the number of test runs also shall be reported.

2.7.2.2 Power and energy data shall be recorded, averaged, and reported from two test runs in opposite directions on the test route. The power and energy transferred through the powertrain and through each of the components of the powertrain shall be recorded.

2.7.2.3 Recharge energy into the battery charger and into the battery shall be recorded, averaged and reported for the two tests per cycle described in 2.7.2.2.

2.7.2.4 Battery voltage and current (power and energy) and the motor voltage and current shall be recorded and repeat test runs averaged and reported as specified under the respective tests.

2.7.2.5 Perform the following checks prior to each day of testing:

2.7.2.5.1 Ensure that all fluid levels are as specified in the vehicle manufacturer's log book: Battery _____, Brake _____, Automatic Transmission _____, Power Steering _____, Other _____.

2.7.2.5.2 Check all electrical power connections for physical tightness and evidence of running hot.

2.7.2.5.3 Inspect tires for damage and wear.

2.7.2.5.4 Torque all wheel lug nuts to vehicle manufacturer's recommended values.

2.7.2.5.5 Set tire pressures and record pressures on data sheets.

2.7.2.5.6 Ensure that the fifth wheel tire pressure meets manufacturer's recommendations.

2.7.2.5.7 Install tape in recorder and record reel number and tracks used on data sheet.

2.7.2.5.8 Record instrumentation channel identities.

2.7.2.5.9 Record driver and observer identities. Weigh the test vehicle and record weight.

2.7.2.5.10 Record wind direction, wind speed and ambient temperature. (Do not undertake testing if wind speeds are greater than 10 mph or if gusts exceed 15 mph.) Record wind direction, velocity, and ambient temperature midway through the test period and at the end of the test period.

2.7.2.5.11 Warm up and stabilize the electronics before beginning tests.

2.7.2.5.12 Obtain pretest zeros and electrical step calibrations. Repeat at the completion of a series of tests or at the end of a test day.

2.7.2.6 Perform the following checks prior to each test:

2.7.2.6.1 Ensure that the proper or sufficient amount of charge is in the battery.

2.7.2.6.2 Ensure that there is sufficient tape in the recorder.

2.7.2.6.3 Record run to be made, direction and course, on the data sheet.

2.7.2.6.4 Other pertinent checks and facts about the test.

2.8 Tests

2.8.1 Range at Steady Speed

2.8.1.1 Purpose of Test - The purpose of this test is to determine the maximum range an electric road vehicle can achieve on a level road at a steady speed.

2.8.1.2 Test Procedure - These road tests are to be conducted subject to the test conditions and data requirements described in Sections 2.3 through 2.7. Individual tests shall be started with the vehicle propulsion battery in a full state of charge.

2.8.1.2.1 Road Tests - The vehicle shall be operated in a normal manner and be accelerated under its own power to the preselected test speed. The range tests shall be continued without interruption at the preselected speed which is to be maintained to within ± 5 percent until the vehicle reaches its end of range as defined in Section 2.8.1.2.2. The vehicle range shall be determined as the average of two tests made around a closed test track or in opposite directions over a road test route. The steady speed reported is to be the average speed maintained over the distance traveled.

2.8.1.2.2 Selection of Test Speeds - The test speed selection depends on the top speed capability of the vehicle. The test speeds to be used are specified below in charted form. The 25 mph (40 km/h) base speed agrees with a commonly used foreign reference speed while 45 and 55 mph correlate with expressway speed limits. In addition, the range at the manufacturer's recommended top speed is to be determined. If a manufacturer's recommendation is not available, the top speed will be defined as 95 percent of the minimum speed of the vehicle when driven around the test track at wide open throttle.

VEHICLE TEST SPEEDS FOR SELECTION		VEHICLE TOP SPEED CAPABILITY (MPH)				
Mph	(km/h)	25-34	35-44	45-54	55-64	65 & Over
25	(40)	X	X	X	X	X
35	(56)		X	X		
45	(72)				X	X
55	(88)					X
Manufacturer's Recommended Top Speed or Top Speed as determined in 2.8.1.2.2		X	X	X	X	X

2.8.1.2.3 Definition of End of Range - The end of the driving range is reached when the vehicle speed falls below 95 percent of the initially programmed steady speed or when such other vehicle performance limitation is reached as may be specified by the vehicle manufacturer. For example, if continuing the range test might result in deleterious operation of the battery, the vehicle manufacturer may relate the end of driving to some characteristic of the battery such as terminal voltage under load.

2.8.1.3 Special Data Recording - In addition to recording the data specified in Section 2.7, the following special data shall be reported:

2.8.1.3.1 The test data shall be tabulated and also plotted as a curve showing range as a function of vehicle speed. The actual test points shall be indicated on this curve.

2.8.1.3.2 The battery voltage and current (power and energy) and the motor voltage and current shall be tabulated at the first half-mile point and at a point one-half mile from the end of range.

2.8.1.3.3 The factor(s) involved in determining the end of range as defined in Section 2.8.1.2.2 shall be reported.

2.8.2 Range on a Driving Cycle

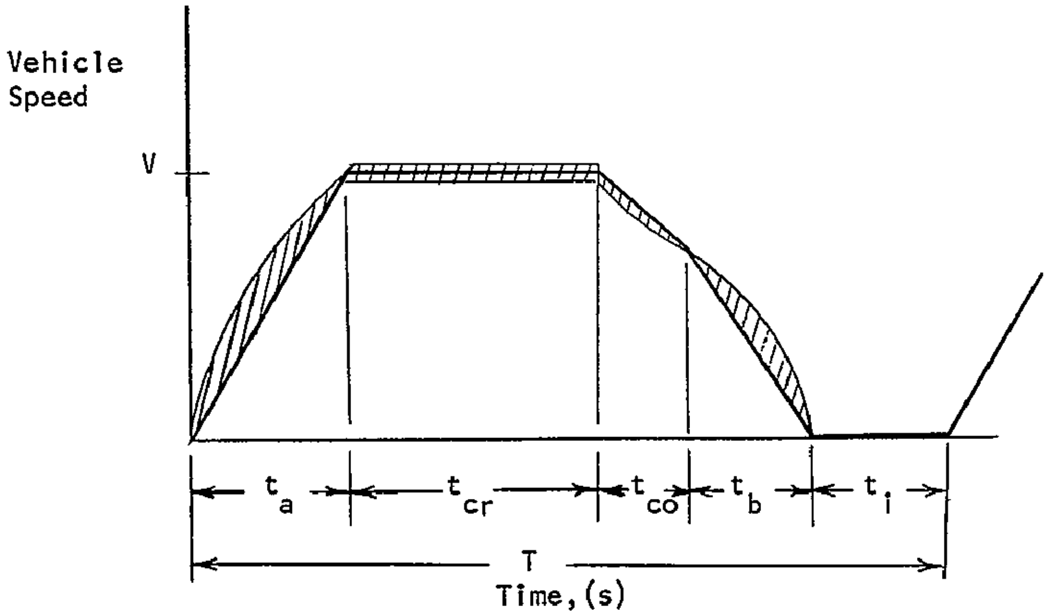


Figure 1 - VEHICLE TEST CYCLE, SAE-J227a

NOTE: The shaded band paths indicate that the velocity profile is tolerant but the time base is carefully stated as shown in Table 1.

TABLE 1. - TEST SCHEDULE FOR REPEATABLE DRIVING PATTERN, SAE-J227a

Schedule	B	C	D
V	32 ± 1.5 km/h (20 ± 1 mph)	48 ± 1.5 km/h (30 ± 1 mph)	72 ± 1.5 km/h (45 ± 1 mph)
t_a	19 ± 1	18 ± 2	28 ± 2
t_{cr}	19 ± 1	20 ± 1	50 ± 2
t_{co}	4 ± 1	8 ± 1	10 ± 1
t_b	5 ± 1	9 ± 1	9 ± 1
t_i	25 ± 2	25 ± 2	25 ± 2
T	72 ± 3	80 ± 3	122 ± 4

NOTE: All times shown are in seconds

2.8.2.1 Purpose of Test - The purpose of this test is to determine the maximum range traveled and the energy consumed by a test vehicle when operated on a level surface in a definite repeatable driving cycle. The driving cycles defined in this procedure are not necessarily intended to simulate a particular vehicle use pattern. Rather it is the intent of this section to provide standard procedures for testing electric road vehicles so that their performance can be cross compared when operated over a fixed driving pattern.

2.8.2.2 Definition of Test Cycles - Three test cycles are defined and shown to allow the vehicle to be tested under conditions which best match its intended use. The three test cycles all have the characteristics shown in Figure 1.

where:
- V = vehicle cruise speed - km/h (mph)
- t_a = acceleration time - s
- t_{cr} = cruise time at speed V - s
- t_{co} = coast time - s
- t_b = braking time to zero speed - s
- t_i = idle time at zero speed - s
- T = total cycle time - s

Values for the parameters of the three test cycles are presented in table 1.

2.8.2.2.1 Driving Schedule B - Schedule B is characterized by a cruise speed of 32 km/h (20 mph) and is intended for use in testing a vehicle designed for use on a fixed route with medium frequency stop and go operation (for example, bakery truck, shuttle bus, postal delivery van, etc.).

2.8.2.2.2 Driving Schedule C - Schedule C is characterized by a cruise speed of 48 km/h (30 mph) and is intended for use in testing a vehicle designed to be used over a variable route with medium frequency stop and go operation (for example, parcel post delivery van, retail store delivery truck, etc.).

2.8.2.2.3 Driving Schedule D - Schedule D is characterized by a cruise speed of 72 km/h (45 mph) and is intended for use in testing a vehicle designed to be used over a variable route in stop and go driving typical of suburban areas (for example, commuter car, etc.).

2.8.2.2.4 Selection of Test Cycles - The test cycles to be selected depend on the acceleration and top speed capabilities of the vehicle. The cycles for selection are charted below:

SAE, J277a		VEHICLE TOP SPEED (MPH)			
TEST SCHEDULES	25-34	35-44	45-54	55-64	65 & Over
B (20 mph)	X	X	X	X	X
C (30 mph)		X	X	(X)**	(X)**
D (45 mph)				X	X

2.8.2.3 Test Procedures - The road tests defined in this procedure are to be conducted subject to the test conditions and data requirements of Sections 2.3 through 2.7. The tests are to be started with the battery fully charged using the vehicle manufacturer's standard procedures.

2.8.2.3.1 Road Tests - The test vehicle shall be operated repeatedly and without interruption over the selected driving schedule on a level road or test track until it reaches its end of range as defined in Section 2.8.2.3.2. The vehicle range shall be determined as the average of at least two tests

** To be tested to "D" schedule if vehicle meets acceleration requirements. If not, the vehicle will be tested to "C" schedule.

made around a closed test track or in opposite directions over a road test route. The steady speed reported is to be the distance traveled divided by the total elapsed time.

2.8.2.3.2 End of Range - The end of the driving range is defined as the end of the driving cycle immediately preceding the cycle in which the vehicle either ceases to meet the requirements of the selected driving schedule or reaches some other vehicle performance limitation specified by the vehicle manufacturer. For example, if continuing the test might result in deleterious operation of the battery, the vehicle manufacturer may relate the end of range to some battery characteristic such as its voltage under load.

2.8.2.4 Special Data Recording - In addition to recording the data specified in Section 2.7, the following special data shall be reported:

2.8.2.4.1 The range achieved, the number of test cycles successfully completed and the test schedule used shall be recorded for each range achieved over at least two tests. The number of tests and the spread of the data also shall be reported.

2.8.2.4.2 The battery voltage and current (power and energy) and the motor voltage and current shall be tabulated and also plotted as a function of time and speed for the third cycle and the last complete cycle of these tests.

2.8.2.4.3 The factor(s) used to define the end of range in Section 2.8.2.3.2 shall be identified and reported.

2.8.3 <u>Acceleration on a Level Road</u>

2.8.3.1 Purpose of Test - The purpose of this test is to determine the maximum acceleration the vehicle can achieve on a level road with the propulsion battery at various initial states-of-charge.

2.8.3.2 Test Procedure - The road tests defined in this section are to be conducted subject to the test conditions, instrumentation and data recording requirements of Sections 2.3 through 2.7.

2.8.3.3 Road Test Procedure

2.8.3.3.1 A suitable, straight, paved test route shall be selected upon which the vehicle can be safely accelerated to speeds near its peak speed.

2.8.3.3.2 The test vehicle is to be accelerated from a standing start at its maximum attainable, or permissible, acceleration rate until either the vehicle's peak speed is reached or until a safe limit speed is attained.

2.8.3.3.3 At least two successive runs shall be made in opposite directions over the test course to establish the vehicle's maximum acceleration characteristics at each of the three battery states-of-charge specified in Section 2.4. The time interval from the end of one acceleration run to the beginning of the next successive acceleration run at each battery state-of-charge shall not exceed 5 minutes.

2.8.3.3.4 Special Data Recording - In addition to recording the data specified in Section 2.7, the following special data shall be reported:

2.8.3.3.4.1 The vehicle's acceleration characteristics shall be tabulated and also plotted as speed versus time for each of the initial states-of-charge, the data to be tabulated and plotted shall be the average results of two runs for that initial state-of-charge (see Figure 2).

2.8.3.3.4.2 The battery current and the motor current shall be tabulated and also plotted as a function of time and of speed for the acceleration characteristics.

2.8.4 Gradeability Limit

2.8.4.1 Purpose of Test - The purpose of this test is to determine the maximum grade on which the test vehicle can just move forward.

2.8.4.2 Test Procedure - Direct measurement of the gradeability limit on steep test grades generally is impractical. Therefore, the gradeability limit is to be calculated from the gross vehicle test weight and the measured tractive force delivered by the vehicle at a speed near zero.

2.8.4.2.1 The tractive force shall be measured on a suitable horizontal surface and is the maximum force which can be maintained by the vehicle propulsion system for a period of 20 s while moving the vehicle at a minimum speed of 1.6 km/h (1 mph).

2.8.4.2.2 The tractive force shall be determined for various battery states-of-charge where the latter are defined in Section 2.4 and at the highest transmission gear ratio (lowest speed).

2.8.4.2.3 Because the high-rate discharge capability of batteries is time dependent, two tractive force tests are to be made for each battery state-of-charge. The lower of the two tractive force measurements shall be used to determine the gradeability limit.

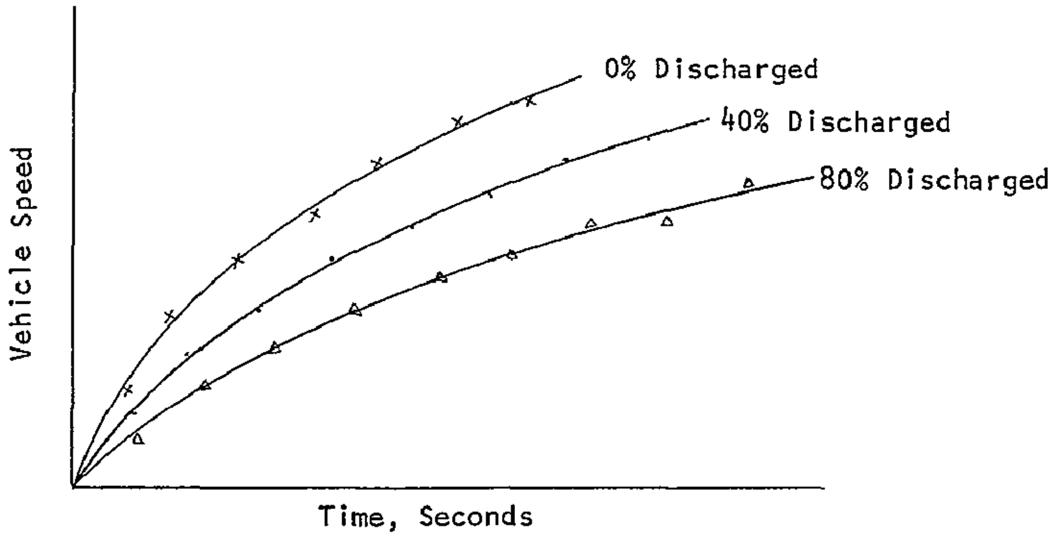


FIGURE 2 - ACCELERATION CHARACTERISTICS

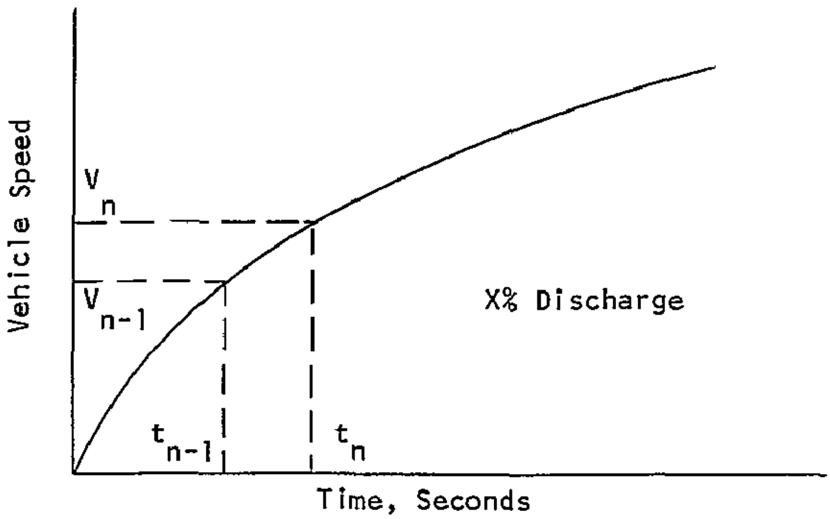


FIGURE 3 - VEHICLE SPEED VERSUS TIME DURING ACCELERATION

2.8.4.3 Calculation of Gradeability Limit - The percent gradeability limit is to be determined using the following relationship:

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

where: P = measured traction force - kg (lb)

W = manufacturer's rated gross vehicle weight - kg (lb)

2.8.4.4 Special Data Requirements - The procedures just defined establish the gradeability limit of the test vehicle as a function of the battery state-of-charge. If the traction force is limited by slippage between the vehicle's drive wheels and the road surface, this fact should be recorded.

2.8.4.5 The battery voltage and current (power) and the motor voltage and current shall be tabulated with the gradeability limit.

2.8.5 <u>Gradeability at Speed</u>

2.8.5.1 Purpose of Test - The purpose of this test is to determine the maximum vehicle speed which can be maintained on roads having different grades. The effect of battery state-of-charge on the vehicle capability is to be brought out in these tests. An analytical method using data collected in Section 2.8.3, "Acceleration Characteristics on a Level Road," is described.

2.8.5.2 Analytical Method - Using the speed-time data from the road tests of Section 2.8.3.3, the vehicle's acceleration characteristics shall be plotted as in Figure 3 for each state-of-charge. Data for successive time intervals then are to be used to determine the vehicle's average acceleration during the nth time interval.

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

when the vehicle has reached the average speed:

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

The data derived from these calculations shall be tabulated and also plotted as average acceleration versus vehicle speed and a smooth curve shall be drawn through the calculated points for each state-of-charge as shown in Figure 4. If the test vehicle is equipped with a recording accelerometer as well as speedometer during the test of Section 2.8.3.3, the information of Figure 4 is obtained directly and can be plotted as illustrated. The percent grade the vehicle is able to traverse at any selected speed is now to be calculated using the following relationship:

$$\text{Percent Gradeability at Speed} = 100 \tan (\sin^{-1} 0.0285a)$$

where: a = vehicle acceleration at the selected speed - km/h.s (mph/s)

The constant 0.0285 in this equation becomes 0.0455 when the vehicle's acceleration is determined in English units of mph/s.

2.8.5.3 Special Data Recording

2.8.5.3.1 The calculated percent gradeability of the vehicle shall be recorded for each test speed and for the three battery inertial states-of-charge specified in Section 2.4.4.

2.8.5.3.2 The battery voltage and current (power) and the motor voltage and current shall be tabulated and also plotted in correspondence with the gradeability at speed.

2.8.6 Road Energy Consumption

2.8.6.1 Purpose of Test - The purpose of this procedure is to determine the power required and energy consumed at varying vehicle speeds to overcome aerodynamic drag and rolling resistance.

2.8.6.2 Test Procedure - Vehicle road power and energy consumption at various steady speeds are to be determined from a coast-down test which shall be performed in the following way:

2.8.6.2.1 Accelerate the test vehicle under its own power on a level road or test track to its maximum safe speed.

2.8.6.2.2 Disconnect the drive motor(s) where possible and allow the vehicle to coast freely to zero speed while recording vehicle speed versus time.

2.8.6.2.3 Repeat the coast-down test at least three times in opposite directions over the road or track to compensate for the effects of wind and grade. Record wind direction and magnitude and grade direction and magnitude for each run.

2.8.6.2.4 During the coast-down tests, the powertrain loads which are coupled to the wheels shall be minimized or removed. If the vehicle has a

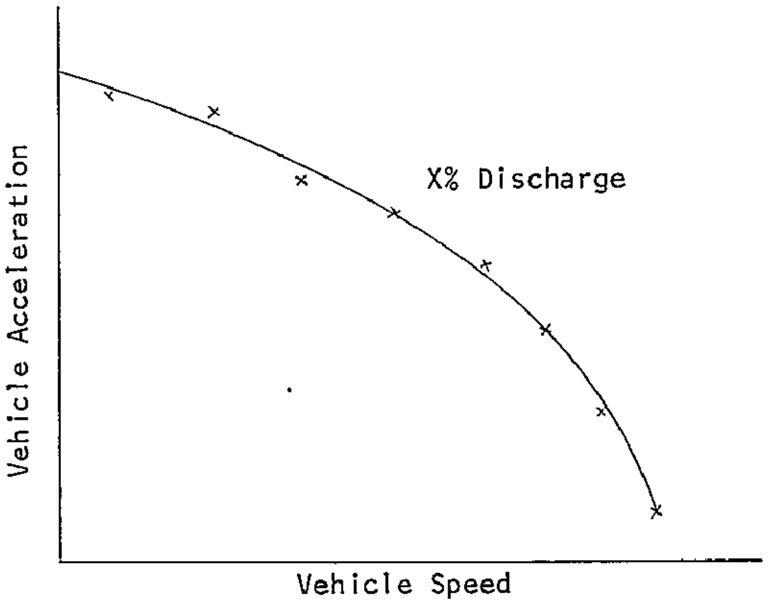


FIGURE 4 - VEHICLE MAXIMUM ACCELERATION VERSUS VEHICLE SPEED

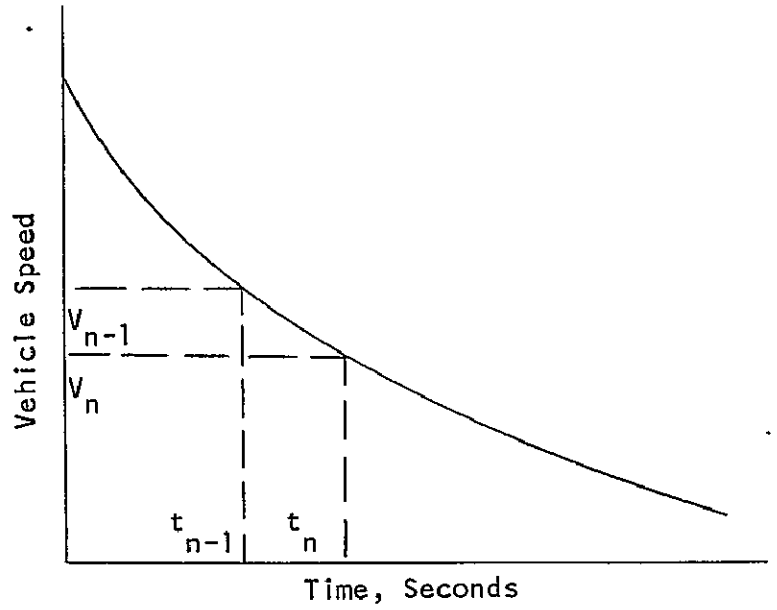


FIGURE 5 - VEHICLE SPEED VERSUS TIME DURING COASTING

transmission then the motor shall be isolated from the drive line by placing it in neutral. If the motor cannot be mechanically isolated*, then both the armature and field of the motor shall be electrically open circuited. A correction factor described in paragraph 2.8.6.4.1 shall be used to compensate for those powertrain loads which cannot be removed easily.

2.8.6.3 Data to be Recorded

2.8.6.3.1 The speed or deceleration of the vehicle shall be recorded as a function of time during the coast-down tests.

2.8.6.3.2 In addition to the general information to be recorded, which is specified in Section 2.7, any special modifications to the vehicle which were made to minimize powertrain loads during the coast-down tests as described in the previous paragraph, shall be recorded.

2.8.6.4 Data Reduction - The vehicle speed versus time data obtained during the coast-down tests shall be processed to establish an average coast-down characteristic for the test vehicle. This characteristic data shall be tabulated and also plotted as shown in Figure 5.

2.8.6.4.1 Vehicle Road Load Power - The vehicle propulsion power required to overcome aerodynamic and rolling resistance is to be determined from Figure 5. From this curve determine the vehicle speed V_n which occurs at successive intervals of time, t_n. The power required, P_n, to propel the vehicle at the average speed, $\overline{V}_n$

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

then shall be determined from the following relationship:

$$\overline{P}_n = 3.86\times10^{-5} W \frac{(V_{n-1}^2 - V_n^2)}{(t_n - t_{n-1})} \quad \text{kW}$$

where: W = Gross Vehicle Test Weight, kg
V = Vehicle Speed, km/h
t = Time, s

The above equation yields the road load power in horsepower when the constant in the equation equals 6.08×10^{-5} and vehicle weight is in pounds. Speed is in miles per hour and time is in seconds.

* Motor windage and bearing losses, etc., are to be determined with the help of the vehicle manufacturer.

The calculated power required at each calculated average value of road speed shall be plotted as illustrated in Figure 6.

2.8.6.4.2 Vehicle Road Energy - The road energy consumed per kilometer in propelling the vehicle at steady speed also can be determined from the coast-down characteristics previously plotted as Figure 5.

Again using the vehicle speed V_n at successive time intervals, t_n, the road energy consumed at the average speed, $\overline{V}_n$

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

shall be determined by the following equation:

$$E = 7.72 \times 10^{-5} \, W \frac{(V_{n-1} - V_n)}{(t_n - t_{n-1})} \cdot \frac{\text{kWh}}{\text{km}}$$

where:
W = Gross Vehicle Test Weight, kg
V = Vehicle speed, km/h
t = time, s

The above equation yields the energy consumption per unit distance in kilowatt hours per mile when the constant in the equation equals 9.07×10^{-5} and the vehicle weight is in pounds, speed is in miles per hour, and time is in seconds.

The calculated road energy consumption per kilometer of travel for each calculated average value of road speed shall be tabulated and also plotted as illustrated in Figure 7.

2.8.6.4.3 Alternate Procedures - The equations of paragraphs 2.8.6.4.1 and 2.8.6.4.2 use speed changes over fixed time intervals to determine an average deceleration rate. The calculations, therefore, yield the average values of power required and energy dissipated during each selected time interval. The average road power required and average road energy consumption were plotted in Figure 6 and Figure 7 against the average speed for each successive time interval. If instantaneous values of vehicle acceleration are available from instruments which record acceleration directly, then instantaneous values of dissipated energy and power required can be determined using appropriate equations to produce the relationships illustrated in these figures.

2.8.6.4.4 Corrections for Powertrain Loads - The values determined using this procedure are to be the power required and energy dissipated external to the vehicle by aerodynamic drag and rolling losses. Corrections, therefore, must be made to the values of energy and power determined in paragraphs

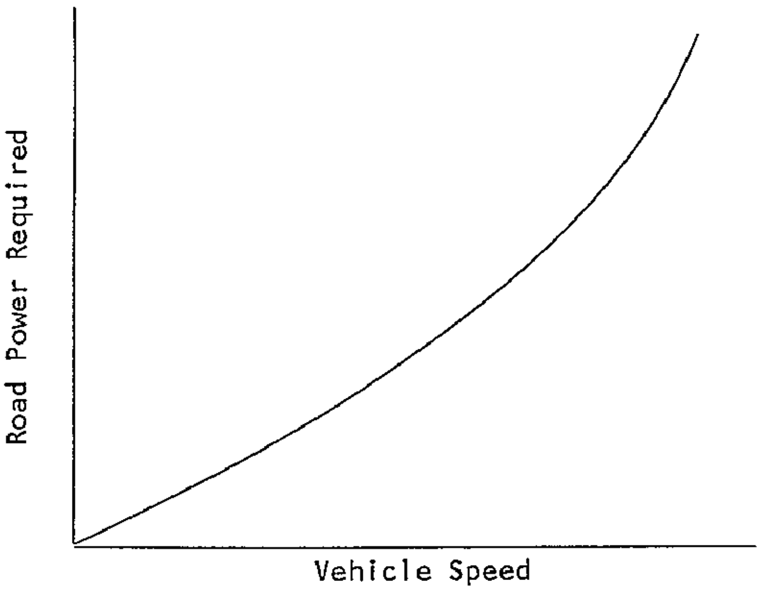


FIGURE 6 - ROAD POWER VERSUS VEHICLE SPEED

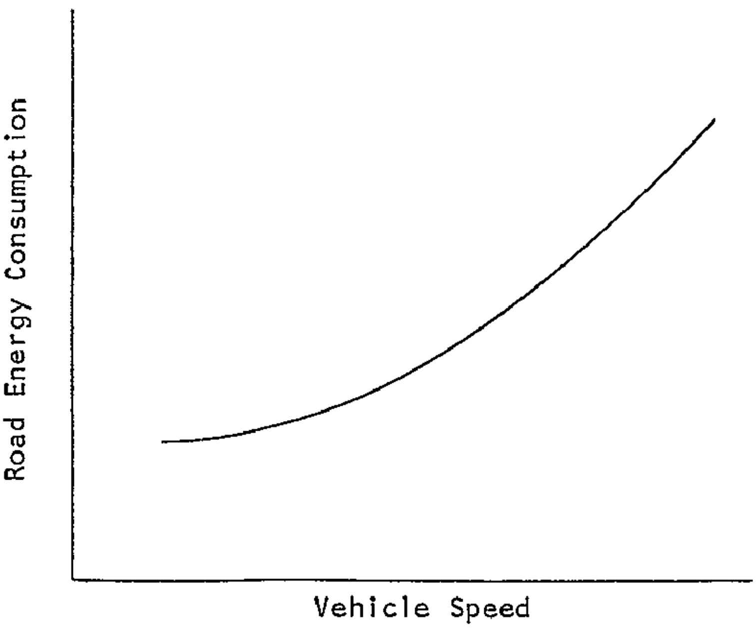


FIGURE 7 - ROAD ENERGY CONSUMPTION VERSUS VEHICLE SPEED

2.8.6.4.1 and 2.8.6.4.2 to compensate for those powertrain loads which could not be eliminated during the coast-down tests. Specifically, the windage and friction losses in the motor and driveline may be significant if they cannot be decoupled. In this case, data describing the windage and friction losses of each component are to be obtained from the component manufacturer. Gear ratios in the driveline then are to be used to relate component speeds to vehicle speed, power required and energy dissipated in the driveline established as a function of vehicle speed. These data can be used to correct values of road energy and power previously obtained and the corrected energy and power curves plotted in a manner similar to Figures 6 and 7.

2.8.7 <u>Vehicle Energy Economy</u>

2.8.7.1 Purpose of Test - The purpose of this test is to define a measure of the overall energy economy of an electric vehicle and to define procedures for its evaluation.

2.8.7.2 Definition of Energy Economy - Energy usage involves the process of charging the battery as well as the consumption of this stored energy for vehicle propulsion. Because the vehicle user pays for charging energy, vehicle energy economy is here defined as the vehicle range in various operating modes divided into the AC energy required to return the battery to its original state-of-charge. The vehicle energy economy, therefore is defined as follows:

$$\text{Vehicle Energy Economy} = \frac{\text{A.C. energy to recharge battery}}{\text{Range in prescribed driving mode}}, \left(\frac{\text{kWh}}{\text{mi}}\right)$$

2.8.7.3 Test Procedure - Tests for determining vehicle range at steady speed and vehicle range over a definite repeated driving cycle have been defined in Sections 2.8.1 and 2.8.2, respectively. Both of these range tests are to be used to establish values for vehicle energy economy.

2.8.7.3.1 Vehicle manufacturer's recommended procedures shall be used to charge the battery to full capacity both before and after the selected range tests.

2.8.7.3.2 A watt-hour meter shall be installed across the A.C. energy source used to charge the battery and the total energy consumed to return the battery to full charge shall be measured following the range test.

2.8.7.4 Data Recording - The range of the vehicle at steady speed or its range over a repeated driving cycle is to be divided into the A.C. energy required to return the battery to its initial state-of-charge as defined above. This quotient shall be reported as the energy economy of the electric vehicle under the particular conditions of the range test. For the case of the continuous speed driving mode and for the case of the repeatable driving pattern, the results should be presented in tabular form for the driving modes tested.

2.8.8 Braking

This section is made up of excerpts from the Federal Motor Vehicle Safety Standards No. 105-75.

2.8.8.1 Purpose of the Tests - The purpose of these tests is to determine the vehicle's braking capability and performance under normal and emergency conditions. This includes stopping distance on dry pavement and also vehicle safety while braking in turns on wet and dry pavement.

2.8.8.2 Test Procedure - Each vehicle shall be capable of meeting all the requirements of the stopping distance when tested according to the procedures and in the sequence set forth below, without replacing any brake system part or making any adjustments to the brake system other than as permitted in burnish and reburnish procedures. Automatic adjusters may be locked out, according to the manufacturer's recommendation, when the vehicle is prepared for testing. If this option is selected, adjusters must remain locked out for entire sequence of tests. A vehicle shall be deemed to comply with the stopping distance requirements if at least one of the stops at each speed and load specified is made within a stopping distance that does not exceed the corresponding distance specified in the table shown in Section 2.8.8.4.

2.8.8.3 Road Test Procedure

2.8.8.3.1 Pretest Instrumentation Check - Conduct a general check of instrumentation by making not more than 10 stops from a speed of not more than 30 mph or 10 snubs* from a speed of not more than 40 to 10 mph at a deceleration of not more than 10 fpsps. If instrument repair, replacement, or adjustment is necessary, make not more than 10 additional stops or snubs after such repair, replacement or adjustment.

2.8.8.3.2 Service Brake Systems Test - This is a pre-burnish brake effectiveness test. It is intended that this test be conducted after the required "B," "C" and/or "D" cycle tests. Also, it is intended that these tests be conducted after a number of snubs equivalent to Section 2.8.8.3.1. The tests are: Make six stops from 30 mph, then make six stops from the manufacturer's recommended maximum speed but no greater than 60 mph.

2.8.8.3.3 Braking in a Turn Test

*A snub is a speed change from a higher speed to a lower speed through braking.

2.8.8.3.3.1 Braking in a Turn on Dry Pavement - Drive the vehicle in a circle that will produce a lateral acceleration (Table 2.8.8.3.6) of .3g using the top speed as determined in 2.8.1.2.2 but no greater than 60 mph. Apply maximum braking but make sure that lockup does not occur on more than one wheel per axle. Under these conditions the vehicle should continue to negotiate the same circular path and be controllable within a 12-foot wide lane. This test is to be repeated three times for right turning and left turning.

2.8.8.3.3.2 Braking in a Turn on Wet Pavement - Drive the vehicle in a circle that will produce a lateral acceleration (Table 2.8.8.3.6) of .2g using the top speed as determined in 2.8.1.2.2 but no greater than 60 mph. Apply maximum braking but make sure that lockup does not occur on more than one wheel per axle. Under these conditions the vehicle should continue to negotiate the same circular path and be controllable within a 12-foot wide lane. This test is to be repeated three times for right turning and left turning.

2.8.8.3.4 Service Brake Water Recovery Test - The service brakes shall be capable of stopping each vehicle in a water recovery test, as specified below. Preceding the brake water recovery test, three baseline check stops shall be made from 30 mph at 10 fpsps. The speed, stopping distance and control force shall be documented. The control force used for the baseline check stops shall be not less than 10 pounds nor more than 60 pounds, except that the control force for a vehicle with a GVW of 10,000 pounds or more may be between 10 and 90 pounds.

(a) After being driven for 2 minutes at a speed of 5 mph in any combination of forward and reverse directions through a trough having a water depth of 6 inches, each vehicle with a GVW of 10,000 pounds or less shall be capable of making five recovery stops from 30 mph at 10 fpsps for each stop with a control force application that falls within the following maximum and minimum limits:

(1) A maximum for the first four recovery stops of 150 pounds, and for the fifth stop, of 45 pounds more than the average control force for the baseline check (but in no case more than 90 pounds, except that the maximum control force for the fifth stop in the case of a vehicle manufactured before September 1, 1976, shall be not more than plus 60 pounds of the average control force for the baseline check (but in no case more than 110 pounds).

(2) A minimum of the average control force for the baseline check minus 10 pounds, or the average control force for the baseline check times 0.60, whichever is lower (but in no case lower than 5 pounds).

2.8.8.3.5 Parking Brake Test - The parking brake tests for any vehicle on different grades, in different directions and for different loads may be conducted in any order. The force required for actuation of a hand-operated brake system shall be measured at the center of the hand grip area or at a distance of 1 1/2 inches from the end of the actuation lever.

2.8.8.3.5.1 Test procedure for requirements in 2.8.8.3.5.3.

2.8.8.3.5.1.1 Condition the parking brake friction elements so that the temperature at the beginning of the test is at any level not more than 150°F (when the temperature of components on both ends of an axle are averaged).

2.8.8.3.5.1.2 Drive the vehicle, loaded to GVW, onto a 30 percent grade (2.8.8.3.5.3) with the longitudinal axis of the vehicle in the direction of the slope of the grade, stop the vehicle and hold it stationary by application of the service brake control, and place the transmission in neutral.

2.8.8.3.5.1.3 With the vehicle held stationary by means of the service brake control, apply the parking brake by a single application of the force specified in (a) or (b), except that a series of applications to achieve the specified force may be made in the case of a parking brake system design that does not allow the application of the specified force in a single application:

(a) In the case of a passenger car, not more than 125 pounds for a foot-operated system and not more than 90 pounds for a hand-operated system.

(b) In the case of a school bus, not more than 150 pounds for a foot-operated system, and not more than 125 pounds for a hand-operated system.

Following the application of the parking brake release all force on the service brake control and commence the measurement of time if the vehicle remains stationary. If the vehicle does not remain stationary, reapplication of the service brake to hold the vehicle stationary, with reapplication of a force to the parking brake control at the level specified in (a) or (b) as appropriate for the vehicle being tested (without release of the ratcheting or other holding mechanism of the parking brake) may be used twice to attain a stationary position.

2.8.8.3.5.1.4 Following observation of the vehicle in a stationary condition for the specified time in one direction, repeat the same test procedure with the vehicle orientation in the opposite direction on the specified 30 percent grade.

2.8.8.3.5.2 Alternate test procedure for requirements of 2.8.8.3.5.3

(a) Check that the transmission must be placed in park position to release key.

(b) Test as in 2.8.8.3.5.1 except in addition place the transmission control to engage the parking mechanism.

(c) Test as in 2.8.8.3.5.1 except on a 20-percent grade, with the parking mechanism not engaged.

2.8.8.3.5.3 Parking Brake System Requirements - Each vehicle shall be manufactured with a parking brake system of a friction type with a solely mechanical means to retain engagement when tested according to the procedures specified in 2.8.8.3.4.1 and .2 and meet the requirements specified below as appropriate, with the system engaged:

(a) In the case of a passenger car, with a force applied to the control not to exceed 125 pounds for a foot-operated system and 90 pounds for a hand-operated system.

(b) In the case of a school bus, with a force applied to the control not to exceed 150 pounds for a foot-operated system and 125 pounds for a hand-operated system.

2.8.8.3.5.3.1 Except as provided in the parking brake system on a vehicle with a GVW of 10,000 pounds or less shall be capable of holding the vehicle stationary (to the limit of traction on the braked wheels) for 5 minutes in both a forward and reverse direction on a 30-percent grade.

2.8.8.3.5.3.2 A vehicle of a type described in previous paragraph at the option of the manufacturer may meet the requirements below instead of the requirements of the previous paragraph if:

(a) The vehicle has a transmission or transmission control which incorporates a parking mechanism.

(b) The parking mechanism must be engaged before the ignition key can be removed. The vehicle's parking brake and parking mechanism, when both are engaged, shall be capable of holding the vehicle stationary (to the limit of traction of the braked wheels) for 5 minutes, in both forward and reverse directions, on a 30-percent grade.

The vehicle's parking brake, with the parking mechanism not engaged, shall be capable of holding the vehicle stationary for 5 minutes, in both forward and reverse directions, on a 20-percent grade.

2.8.8.3.5.3.3 The parking brake system on a vehicle with a GVW greater than 10,000 pounds shall be capable of holding the vehicle stationary for 5 minutes, in both forward and reverse directions, on a 20-percent grade.

TABLE 2.8.8.3.6. - LATERAL (g) FORCES AS A FUNCTION OF VEHICLE VELOCITY AND TURNING RADIUS

Vehicle Velocity			Lateral (g) Acceleration			
			.2	.3	.4	.6
(MPH)	FT/SEC	$(FT/SEC)^2$	RADIUS FOR TURNING VEHICLE			
20	29.32	860	132	88	66	44
25	36.65	1343	207	138	104	69
30	43.98	1934	298	199	149	100
37.5	54.97	3022	470	314	235	157
45	65.97	4352	672	466	336	233
Manufacturer's Maximum Recommended Speed			$\frac{V^2}{.2G}$	$\frac{V^2}{.3G}$	$\frac{V^2}{.4G}$	$\frac{V^2}{.6G}$
55	80.63	6501	1003	669	502	334
60	87.96	7737	1194	796	597	398

$G = 32.174 \text{ ft/sec}^2$

TABLE 2.8.8.4. - STOPPING DISTANCES

Vehicle Test Speed (mph)	Stopping Distance in Feet Pre-Burnish Effectiveness Tests and Spike Effectiveness Tests		
	(a)	(b)	(c)
30	57	69	88
35	74	110	132
40	96	144	173
45	121	182	218
50	150	225	264
55	181	272	326
60	216	323	388

Note: (a) Passenger cars

(b) Vehicles other than passenger cars with GVW of 10,000 pounds or less

(c) Vehicles other than passenger cars with GVW greater than 10,000 pounds

2.8.9 Handling. - The purpose of this test section is to determine the turning diameter and the stability of the vehicle in turning and maneauvering situations.

2.8.9.1 Minimum Turning Diameters - Perform this test on a skid pad or other flat and dry pavement surface.

2.8.9.1.1 Minimum Left Turning Diameter - With the vehicle speed at approximately 1 mph (1.6 km/h) turn the steering wheel left to its maximum extent and complete two revolutions of driving the vehicle. Measure the diameter of the circle described.

2.8.9.1.2 Minimum Right Turning Diameter - With the vehicle speed at approximately 1 mph (1.6 km/h) turn the steering wheel right to its maximum extent and complete two revolutions of driving the vehicle. Measure the diameter of the circle described.

2.8.9.2 Steady State Yaw Response - This is an optional test and is to be performed only when called out to be done in the test plan. For this test, the vehicle is to be brought up to speed on a tangent to a constant radius course and at the tangent it is to be turned onto the circumference. The turn will continue and data will be recorded in the steady state condition. Three clockwise and three counter-clockwise test runs will be made at each of three velocities (25, 37.5 and 45 mph) and two lateral accelerations (0.4 and 0.6g) for a total of 36 test runs.

2.8.9.2.1 Test Facilities Preparation

2.8.9.2.1.1 Record the value and the test date of the current skid number measurements applicable to the courses to be used. If not available, measure the skid number.

2.8.9.2.1.2 Ensure that the marking on the 100 foot-radius and 238 foot-radius circles provides adequate visual contrast. Mark the test initiation points with cones.

2.8.9.2.1.3 Prepare the remaining test courses by measuring and marking the non-surveyed courses. Mark the turn initiation points with cones.

2.8.9.2.2 Test Vehicle Preparation - In addition to the vehicle preparation schedules in Sections 2.3, 2.4 and 2.7, the following preparations are required.

2.8.9.2.2.1 Install and check out the steering machine if it was not done previously.

2.8.9.2.2.2 Calibrate the steering machine by driving on a marked radii at speeds that will yield lateral accelerations of 0.4 and 0.6g. Construct a calibration plot whereby the required steering wheel angle may be read as a function of path radius for the two lateral accelerations.

2.8.9.2.2.3 Install and check out instrumentation as required.

2.8.9.2.3 Test Performance Sequence - On the way to the track skid pad, warm up and stabilize the electronics. Start the spin motors on the stabilized platform, uncage and erect to horizontal position (Hunphrey Package or equivalent). Set steering machine to the angle and direction required for the test. Record run direction, course radius and nominal lateral acceleration on the test data sheet.

2.8.9.2.3.1 Drive vehicle onto the track to approach the turn initiation point at the required speed.

2.8.9.2.3.2 Turn on the tape recorder and steering machine ready switch 5 seconds prior to reaching turn initiation point.

2.8.9.2.3.3 At turn initiation point, operate the master start switch which marks the test start and engages the steering machine.

2.8.9.2.3.4 Record data for 5 seconds unless limited to shorter durations by skid pad bounds. (A lower run time limit of 3 seconds will be observed.)

2.8.9.2.3.5 At the conclusion of the run, shut off the master switch and take over steering to remain on the paved surface.

2.8.9.2.3.6 Shut off the tape recorder 2 seconds after the turn is completed.

2.8.9.2.3.7 Repeat steps .1 through .6 in opposite direction.

2.8.9.2.3.8 Repeat steps .1 through .7 two more times for each speed and lateral acceleration combination.

2.8.9.2.4 Data Analysis - Average yaw-rate-front wheel angle between 0.0 and 3.0 seconds will be determined for each test run. The three data points at each combination of test velocity, radius, and turn direction will then be averaged and plotted on a second-degree curve by the method of least squares.

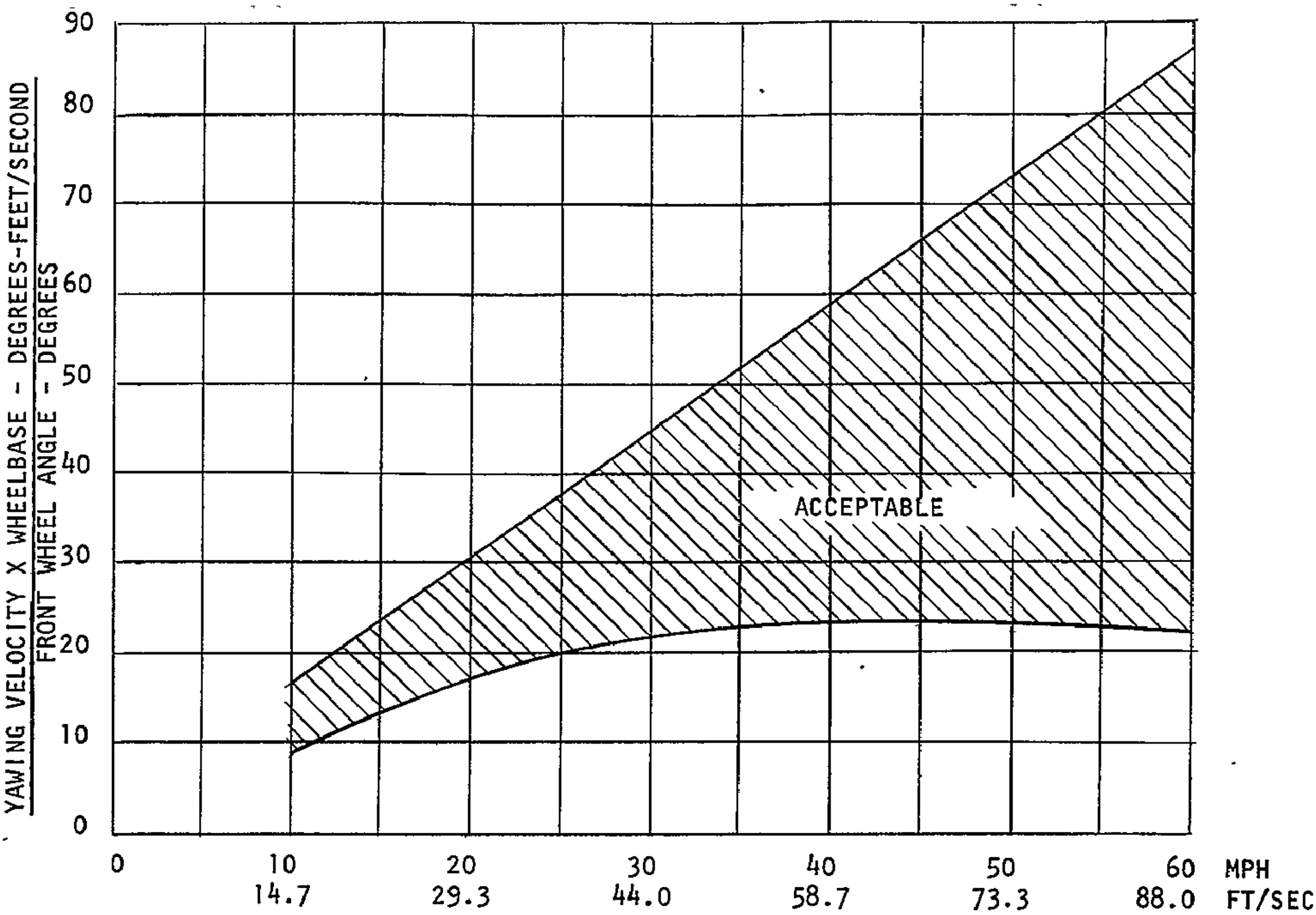


Figure 8 - Steady-State Yawing Velocity Versus Tangential Velocity

The computation of a calculated lateral g based on the measured velocity and the nominal turn radius will also be provided.

A statistical analysis of the data will be performed to determine the mean value, standard deviation and tolerance interval of the yaw rate/front wheel angle data for each test condition. (Tolerance interval is defined as a 90-percent confidence that 90 percent of the samples are within the interval.)

2.8.9.2.5 Data Acquisition System - Data will be tape recorded on-board. The block diagram shown in Figure 9 represents a data acquisition system arrangement.

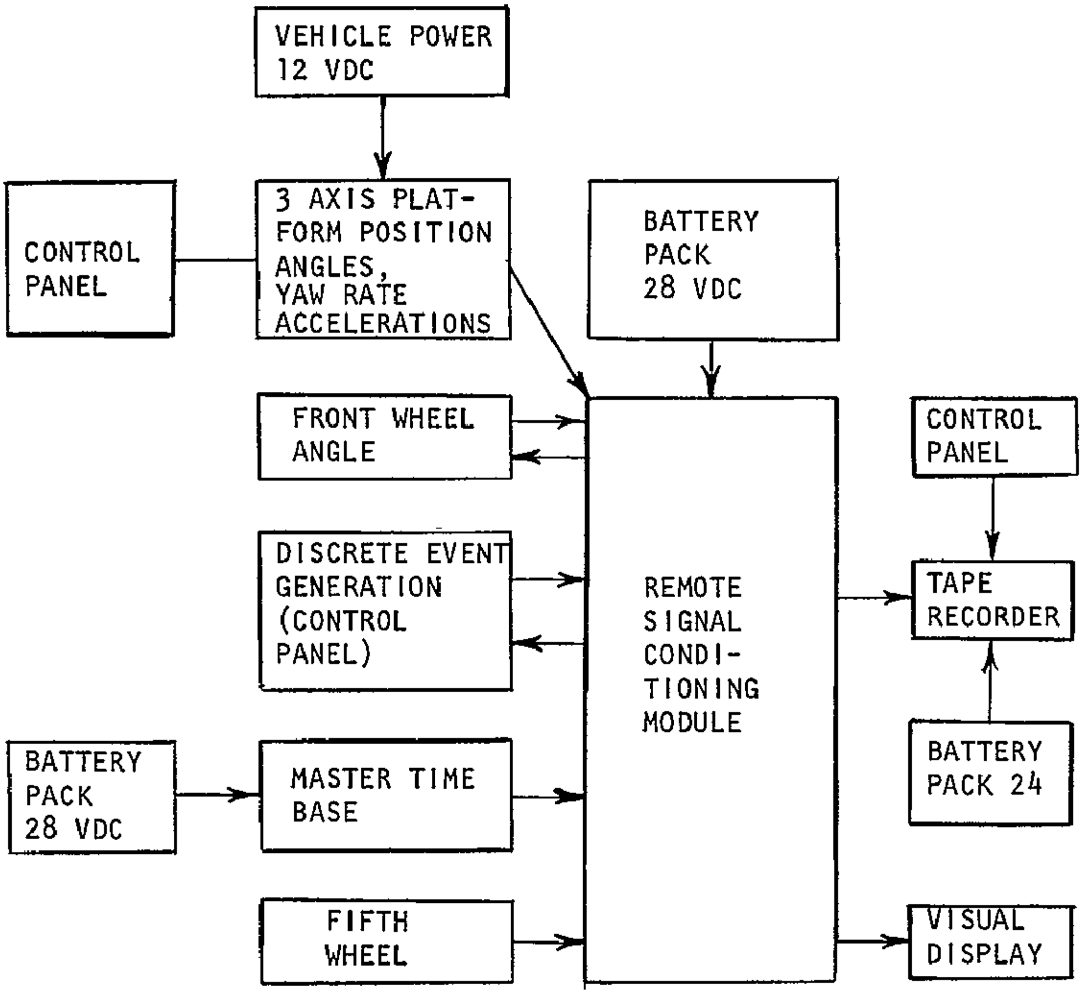


Figure 9 - Data Acquisition Setup for Handling Test Series

A control console will provide remote operation of the tape recorder and visual displays of test control, test status and equipment status parameters. The visual displays will consist of an analog readout of required test control parameters (velocity and yaw rate) and a readout of test-start time and test-stop time. The control console will accept inputs from the

Remote Signal Conditioning Module (RSCM) or directly from the transducer as illustrated in Figure 10.

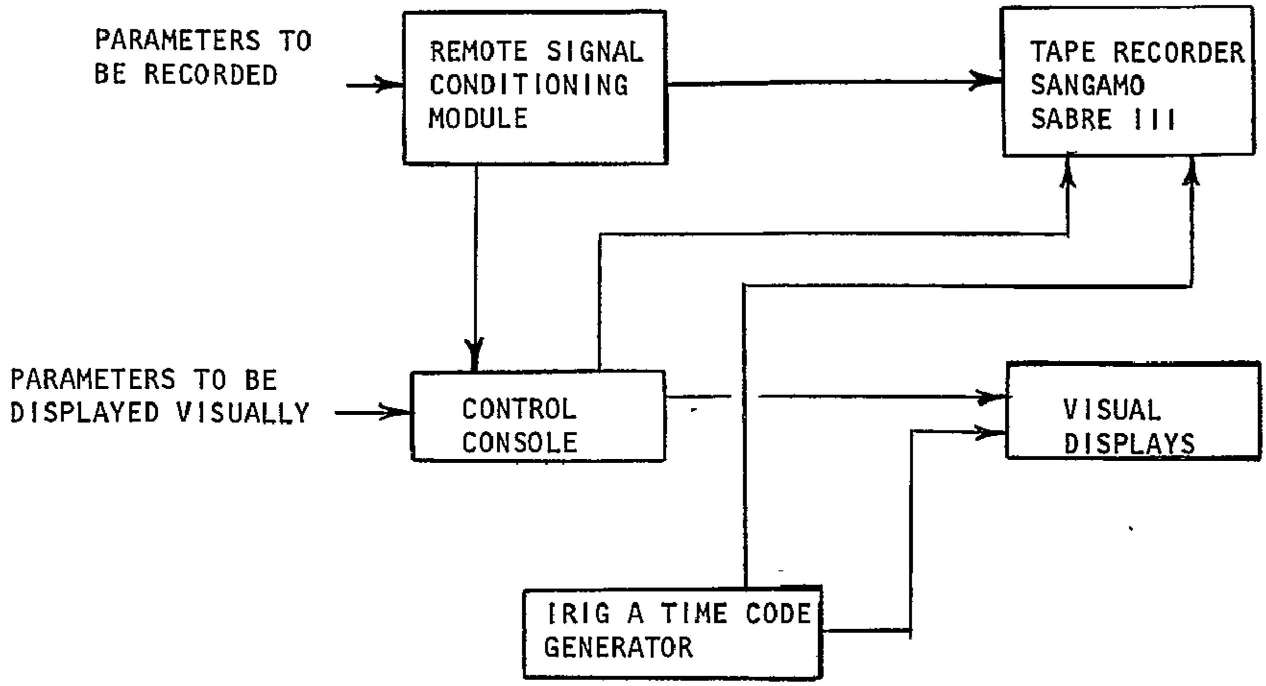


Figure 10 - Accident Avoidance Test Control Setup

The RSCM will provide all signal conditioning, electrical calibration and amplification for recording onto the magnetic tape. Each RSCM can handle 14 data channels and will provide an FM/FM multiplexed signal as output. Figure 11 shows the system diagram defining the RSCM.

Data will be recorded with a Sangamo Sabre III (or equivalent) tape recorder with 14 direct record amplifiers. A special modification provides control of each individual amplifier, allowing track-by-track selection of the recording heads, thus minimizing tape changes by allowing multiple sets of data to be recorded on successive passes of the same tape.

2.8.9.2.6 Test Requirements

2.8.9.2.6.1 Evaluation Criteria - In response to a steering input for which the lateral acceleration is 0.4g $\pm$ 0.02, the vehicle must:

2.8.9.2.6.1.1 Maintain a steady state yaw response at forward velocities of 36.7 feet per second (25 mph), 54.97 feet per second (37.5 mph) and 65.97 feet per second (45 mph) within the envelope defined in Figure 8.

2.8.9.2.6.1.2 Within this envelope, the specific vehicle's response curve must be concave downward at all points. Similar response curves obtained with different lateral accelerations shall exhibit the same characteristic shapes. In relation to the 0.4g yaw response curve on Figure 8 coordinates, as lateral acceleration increases from 0.4g, the yaw response curve shall move downward progressively.

2.8.9.2.6.2 Data and Instrumentation Requirements - The Handling Test Instrumentation Package defined in Table 2.8.9.2.7 is installed in the vehicle for this test series. Channels 1, 2, 3, 4, 5, 8, 9 and 12 will be recorded continuously. Data such as run direction and nominal yaw rate will be recorded manually in the run record log sheets.

2.8.9.2.6.3 Facilities and Equipment - The radial arc requirements for each of the 12 test conditions are shown in Table 2.8.9.2.8. The arc paths are shown in Figure 14, the values in the shaded portion of Table 2.8.9.2.8 can be accomplished in full circles. During the tests at the larger radii the vehicle will accelerate on the loop portion of the track. The resultant partial radii test parameters are shown in Table 2.8.9.2.9. The values shown include a margin for marking a decelerating turn on the 300 foot outside radius of the skid pad at the end of the test. For clarity, only one of the two directions is shown; the alternate direction is obtained by symmetry. The shaded areas in Figure 14 are available as overruns.

2.8.9.3 Transient Yaw Response - <u>This is an optional test and is to be performed only when called out to be done in the test plan.</u> For this test, the vehicle is to be brought up to test speed on a tangent to a constant radius course and at the tangent point, the vehicle is to be turned onto the circumference. The turn is to continue and data is to be recorded through the transient into the resultant steady state condition. Five clockwise and five counterclockwise test runs are to be made at each of two velocities (25 and 45 mph) with a lateral acceleration of 0.4g for a total of 20 test runs.

2.8.9.3.1 Test Facilities Preparation (See 2.8.9.2.1)

2.8.9.3.2 Test Vehicle Preparation (See 2.8.9.2.2)

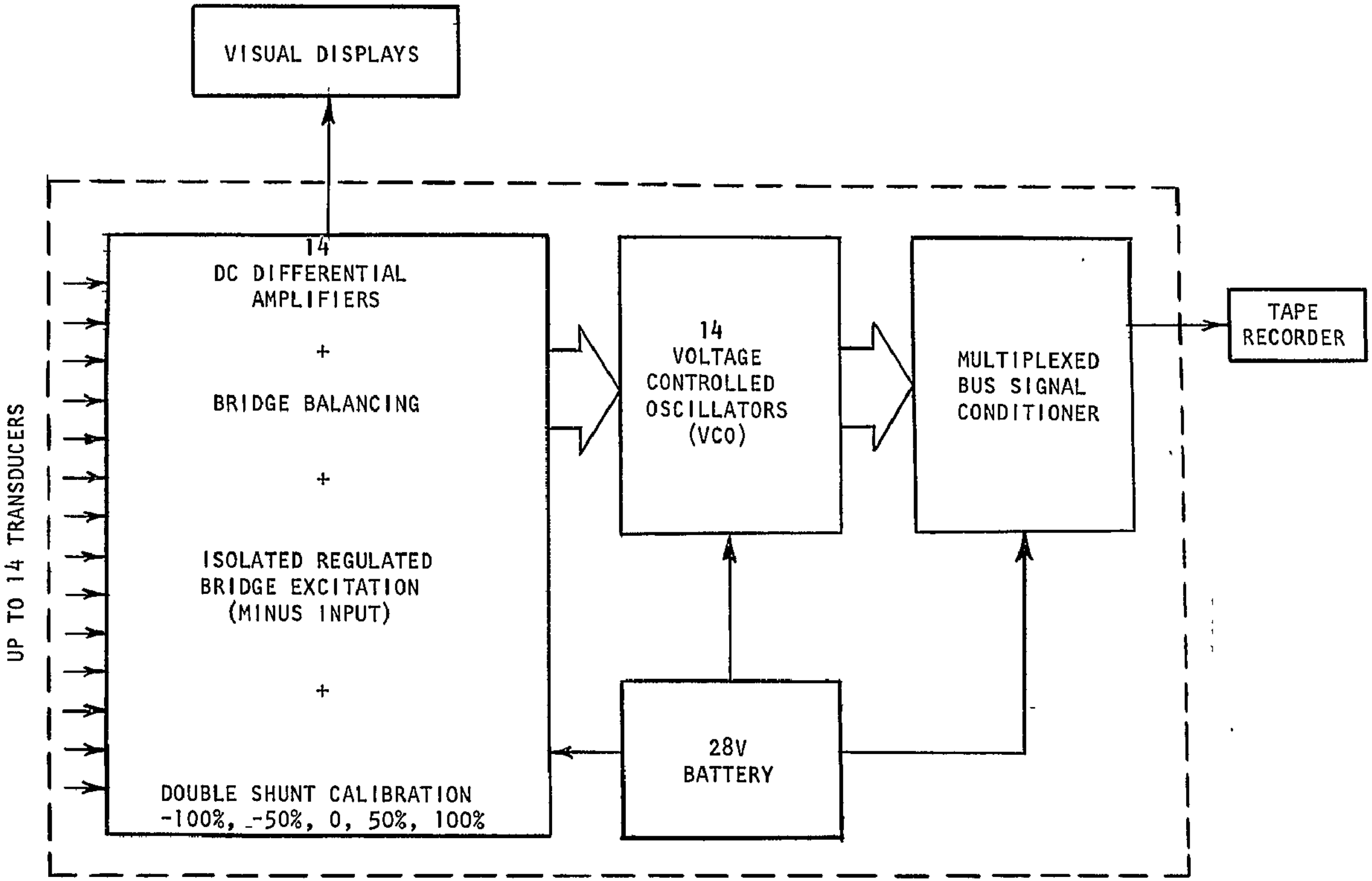


Figure 11 - Remote Signal Conditioning Module (RSCM)

TABLE 2.8.9.2.7 - HANDLING TEST INSTRUMENTATION PACKAGE

Data Item Reference Number (1)	Measurand	Type Transducer	Instrument Manufacturer	Model Number	Full-Scale Range	Transducer Accuracy
①	Vehicle Velocity	Fifth Wheel	Labeco	TT481	150 ft/sec	±0.15 ft/sec
②	Longitudinal Acceleration	Servo Force Balance Accelerometer	Kistler	3036	±1.0G	±0.01G
③	Lateral Acceleration	Servo Force Accelerometer	Kistler	3036	±1.0G	±0.01G
④	Vehicle Yaw Rate	Rate Gyro	Hunphrey	RG51-0343	±40°/sec	±0.6°/sec
⑤	Vehicle Heading Angle	Position Gyro	Hunphrey	18-0902-1	±178°	±0.2°
6	Roll Angle	Position Gyro	Hunphrey	18-0902-1	±30°	±0.2°
7	Pitch Angle	Position Gyro	Hunphrey	18-0902-1	±30°	±0.2°
⑧	Steering Wheel Angle	10 Turn Precision Potentiometer	Helipot	Series	±1800°	±2.5°
⑨	Front Wheel Angle	Linear Potentiometer	Houston Scientific	1800-10-B	±5.0 in	±0.05 in
10	Throttle Position	Linear Potentiometer	Bourns	20015 64801	2.5 in	±0.05 in
11	Steering Wheel Torque	Precision Spring Scale	Chatillon	None	4.5 lb	±0.03 lb
⑫	Time Marker	Switch	Not Applicable	Not Applicable	Not Applicable	Not Applicable

(1) Data to be recorded continuously is circled.

TABLE 2.8.9.2.8 TEST CONDITIONS FOR STEADY STATE YAW RESPONSE TEST, TURN RADII (FT)			
Velocity (mph)	Lateral Acceleration (g)		
	0.2	0.4	0.6
25	207	100	69
37.5	470	238	157
45	672	336	233
55	1003	502	334
Shaded values will be accomplished with complete circles			

TABLE 2.8.9.2.9 PARTIAL RADII RESULTANT TEST PARAMETERS			
V (mph)	R (ft)	Path Length (ft)	Time (sec.)
37.5	470	785	14.3
45	336	699	10.6
45	672	1306	19.8
55	334	540	6.7
55	502	613	7.6
55	1003	726	9.0

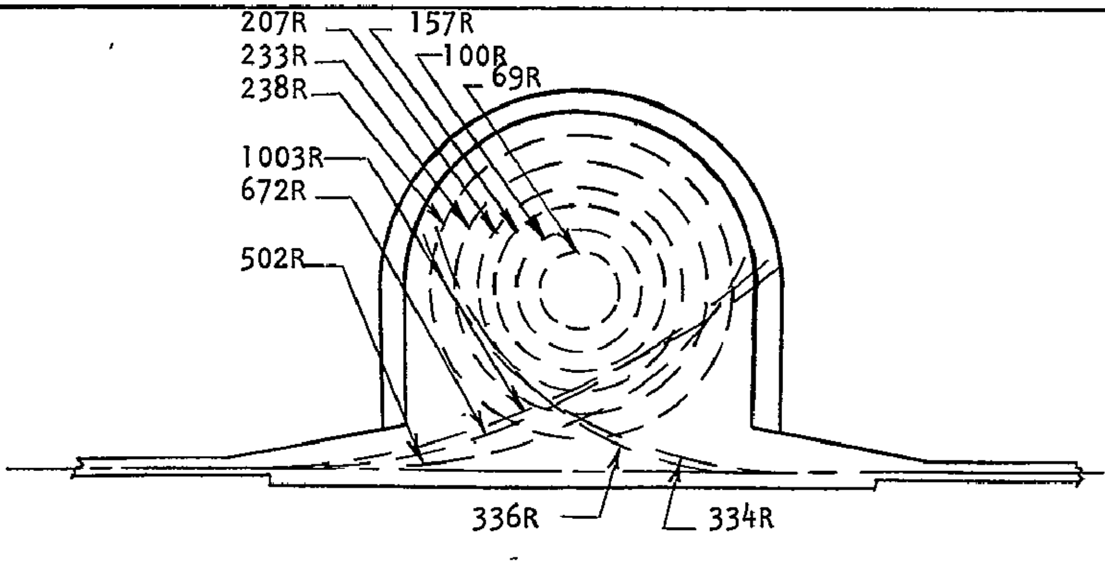


Figure - 12 Skid Pad Steering Performance Trajectories

2.8.9.3.3 Test Performance Sequence - See 2.8.9.2.3 except for 2.8.9.2.3.8. The instruction for the transient yaw test should read "Repeat steps .1 through .7 four more times for each speed at the lateral acceleration of 0.4g."

2.8.9.3.4 Data Analysis - Yaw Rate - front wheel angle (percent of steady state) ratio will be calculated for each run at 0.1 second intervals. The five data points at each of the four combinations of turn direction and test velocity will then be averaged and a second-degree curve plotted by the method of least squares.

A statistical analysis of the transient yaw data at the specification limit breakpoints (0.2, 0.4, 0.8, 1.6 seconds and peak overshoot time) will be performed to determine the mean value, standard deviation, and tolerance interval for each test condition. (Tolerance interval is defined as a 90 percent confidence that 90 percent of the samples are within the interval.)

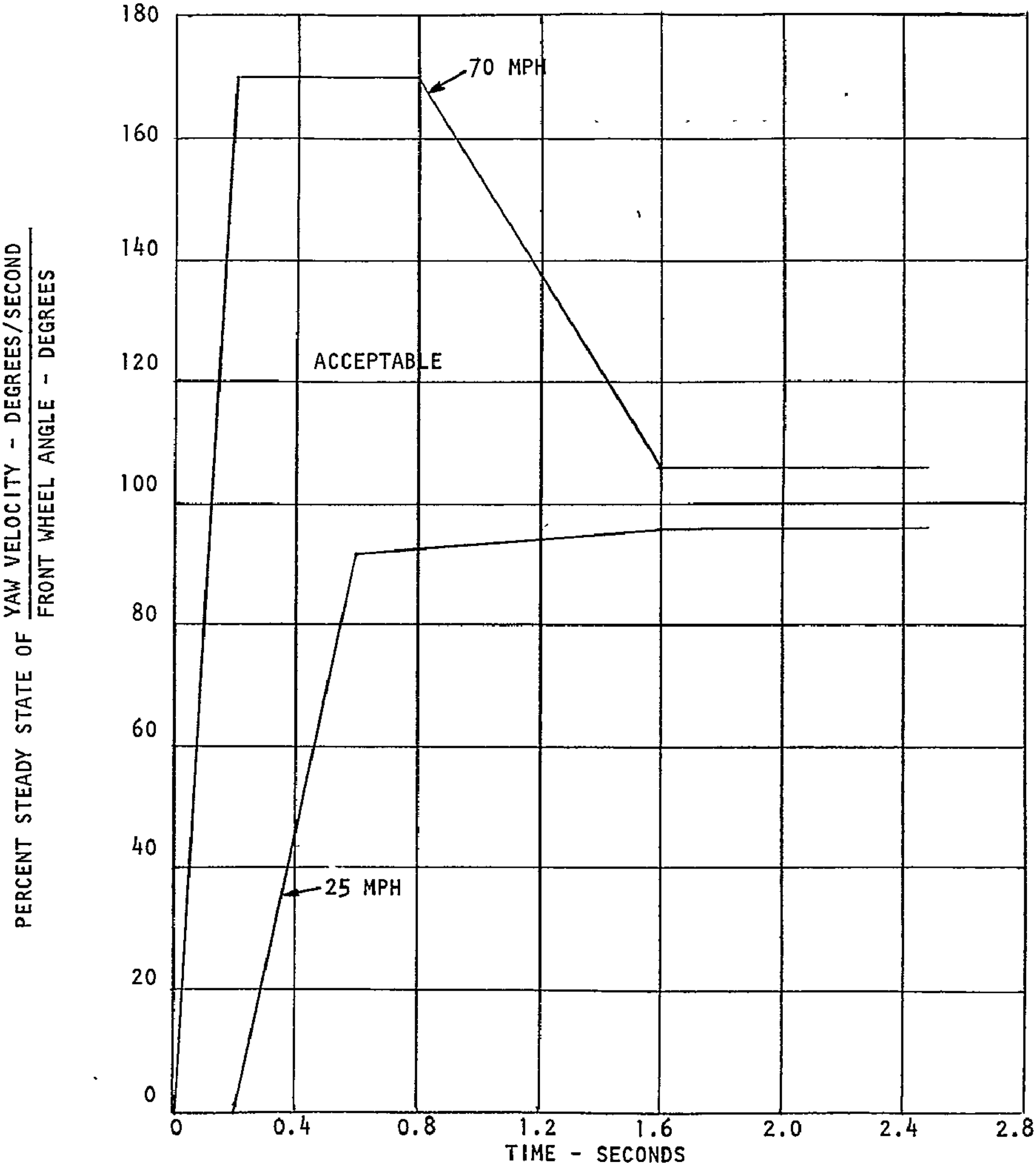


Figure 13 - Transient Yaw Response Versus Time

The computation of a calculated lateral g based on the measured velocity and the nominal turn radius will also be provided.

2.8.9.3.5 Data Acquisition System (See 2.8.9.2.5)

2.8.9.3.6 Test Requirements

2.8.9.3.6.1 Evaluation Criteria - The transient yaw response shall be within the envelope described in figure 13. In this figure, the upper curve is the upper limit for a test speed of 45 mph while the lower curve is a lower limit for a test speed of 25 mph. In addition, the initiation time (T_o) is defined as the instant at which 50 percent of the required steering wheel deflection has been accomplished.

2.8.9.3.6.2 Data and Instrumentation Requirements - The Handling Test Instrumentation Package described in table 2.8.9.3.7 will be installed in the vehicle for this test. Channels 1, 2, 3, 4, 5, 8, 9, and 12 will be recorded continuously. Data such as run direction and nominal yaw rate will be recorded manually in the run record log sheets.

2.8.9.3.6.3 Facilities and Equipment - A skid pad will be utilized (as shown in figure 14). During the tests on the larger radius, the vehicle will be accelerated on the loop portion of the track. For clarity, only one of the two directions is shown; the alternate direction is obtained by symmetry. The courses shown are indicated by flat markers placed on the pavement. The shaded areas in figure 14 are available as overruns.

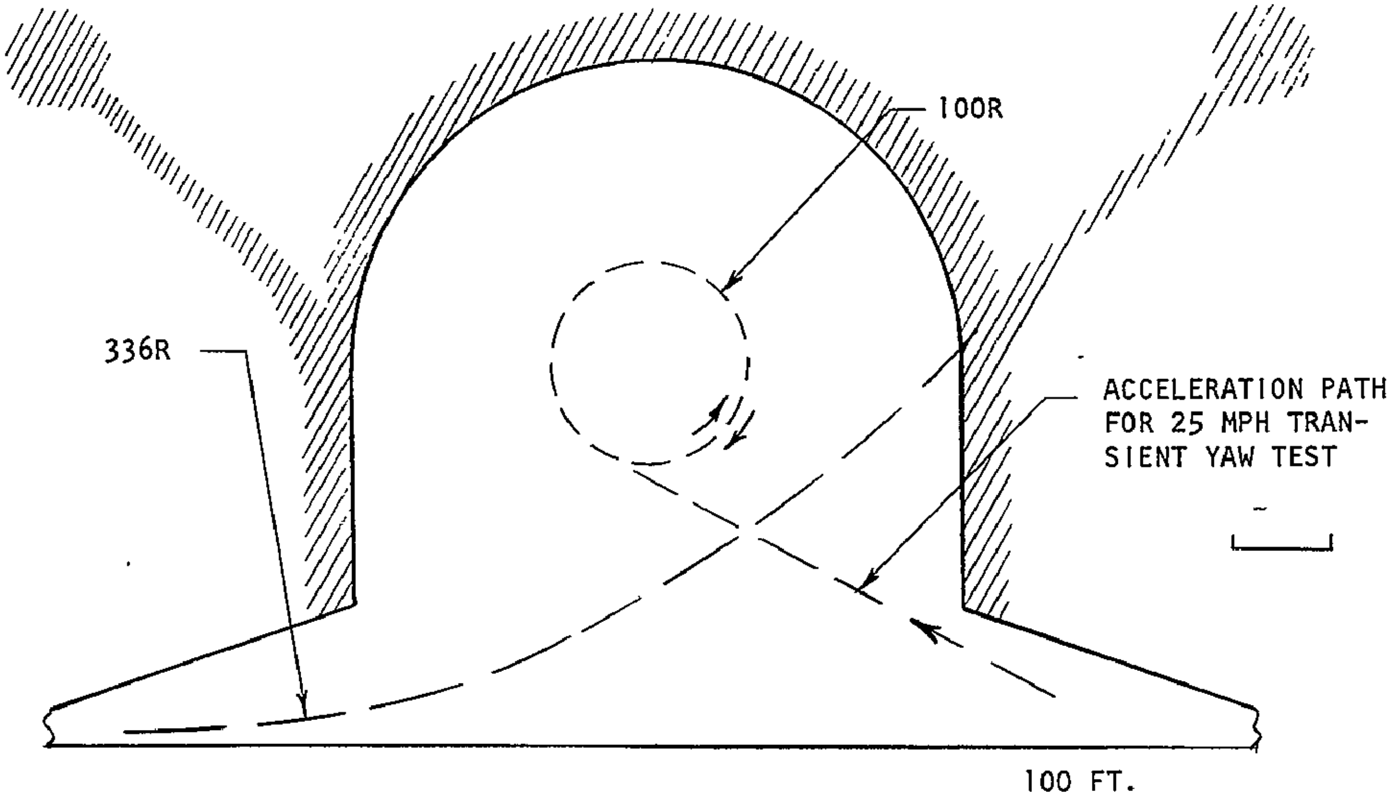


Figure 14 - Skid Pad Showing Steering Performance Trajectories

TABLE 2.8.9.3.7 - HANDLING TEST INSTRUMENTATION PACKAGE

Data Item Reference Number (1)	Measurand	Type Transducer	Instrument Manufacturer	Model Number	Full-Scale Range	Transducer Accuracy
①	Vehicle Velocity	Fifth Wheel	Labeco	TT481	150 ft/sec	±0.15 ft/sec
②	Longitudinal Acceleration	Servo Force Balance Accelerometer	Kistler	3036	±1.0G	±0.01G
③	Lateral Acceleration	Servo Force Accelerometer	Kistler	3036	±1.0G	±0.01G
④	Vehicle Yaw Rate	Rate Gyro	Hunphrey	RG51-0343	±40°/sec	±0.6°/sec
⑤	Vehicle Heading Angle	Position Gyro	Hunphrey	18-0902-1	±178°	±0.2°
6	Roll Angle	Position Gyro	Hunphrey	18-0902-1	±30°	±0.2°
7	Pitch Angle	Position Gyro	Hunphrey	18-0902-1	±30°	±0.2°
⑧	Steering Wheel Angle	10 Turn Precision	Helipot	Series	±1800°	±2.5°
⑨	Front Wheel Angle	Linear Potentiometer	Houston Scientific	1800-10-B	±5.0 in	±0.05 in
10	Throttle Position	Linear Potentiometer	Bourns	20015 64801	2.5 in	±0.05 in
11	Steering Wheel Torque	Precision Spring Scale	Chatillon	None	4.5 lb	±0.03 lb
⑫	Time Marker	Switch	Not Applicable	Not Applicable	Not Applicable	Not Applicable

(1) Data to be recorded continuously is circled.

APPENDIX 1

VEHICLE SUMMARY DATA SHEET

1. Vehicle Manufacturer: Name and Address

2. Description: Model Name and Number, Identification Number, Brief Explanation of the Vehicle's Operating Features, Powertrain, Drivetrain, Regenerative Braking, etc.

3. Price and Availability:

4. Vehicle Weight

    4.1 Curb Weight

    4.2 Gross Vehicle Weight

    4.3 Cargo

    4.4 Passengers

    4.5 Payload

5. Vehicle Size

    5.1 Wheelbase

    5.2 Length

    5.3 Width

    5.4 Head Room

    5.5 Leg Room

    5.6 Number of Seats

6. Auxiliaries and Options

    6.1 Lights: Number, Type, and Function

    6.2 Windshield Wipers:

6.3 Windshield Washers:

6.4 Defroster

6.5 Heater

6.6 Radio

6.7 Fuel Gauge

6.8 Amperemeters

6.9 Tachometer

6.10 Speedometer

6.11 Odometers

6.12 Right or Left Hand Drive

6.13 Transmission

6.14 Regenerative Braking

6.15 Mirrors

6.16 Power Steering

6.17 Power Brakes

6.18 Other

7. Batteries

7.1 Propulsion Batteries

7.1.1 Type and Manufacturer

7.1.2 Number of Modules and Serial Numbers

7.1.3 Number of Cells

7.1.4 Operating Voltage

7.1.5 Capacity

7.1.6 Size

7.1.7 Weight

7.1.8 History: Age, Cycles, etc.

7.2 Auxiliary Battery

7.2.1 Type and Manufacturer

7.2.2 Number of Calls

7.2.3 Operating Voltage

7.2.4 Capacity

7.2.5 Size

7.2.6 Weight

8. Controller

8.1 Type and Manufacturer

8.2 Voltage Rating

8.3 Current Rating

8.4 Size

8.5 Weight

9. Propulsion Motor

9.1 Type and Manufacturer

9.2 Insulation Class

9.3 Voltage Rating

9.4 Current Rating

9.5 Horsepower (Rated and Max. 5 Min Rating)

9.6 Size

9.7 Weight

9.8 Rated Speed and Maximum Speed

10. Battery Charger

10.1 Type and Manufacturer

10.2 On or Off Board Type

10.3 Input Voltage Required

10.4 Peak Current Demand

10.5 Recharge Time

10.6 Size

10.7 Weight

10.8 Automatic Turnoff Feature

11. Body

11.1 Type and Manufacturer

11.2 Materials

11.3 Number of Doors and Type

11.4 Number of Windows and Type

11.5 Number and Type of Seats

11.6 Cargo Space Volume

11.7 Cargo Space Dimensions

12. Chassis

12.1 Frame

12.1.1 Type and Manufacturer

12.1.2 Material

12.1.3 Modifications

12.2 Springs and Shocks

12.2.1 Type and Manufacturer

12.2.2 Modifications

12.3 Axles

12.3.1 Type and Manufacturer

12.3.2 Front

12.3.3 Rear

12.4 Transmission

12.4.1 Type and Manufacturer

12.4.2 Ratios

12.4.3 Driveline Ratio

12.5 Steering

12.5.1 Type and Manufacturer

12.5.2 Ratio

12.5.3 Turning Diameter

12.6 Brakes

12.6.1 Front

12.6.2 Rear

12.6.3 Parking

12.6.4 Regenerative

12.7 Tires

12.7.1 Type and Manufacturer

12.7.2 Size

12.7.3 Pressure

12.7.4 Rolling Radius

13. Performance Data:

Date Taken:

Ambient Conditions:

Comments and Observations

13.1 Manufacturer Specified Maximum Speed:

13.2 Manufacturer Recommended Maximum Cruise Speed:

13.3 Tested at Cruise Speeds:

13.4 Range on Tested Cruise Speeds:

13.5 Tested on Driving Cycles:

13.6 Range on Tested Driving Cycles:

13.7 Acceleration to Maximum Speed

13.8 Acceleration to Recommended Cruise Speed

13.9 Acceleration to 20, 30, 45 mph Cycle Speeds

13.10 Gradeability Limit

13.11 Gradeability at 20, 30, 45 and Cruise Speed

13.12 Road Energy Consumption at 20, 30, 45 and Cruise Speed

13.13 Vehicle Energy Economy on All Cruise Speeds

13.14 Vehicle Energy Economy Driving Cycles:

13.15 Braking Safety in a Turn on a Dry Pavement

13.16 Braking Safety in a Turn on a Wet Pavement

13.17 Stopping Distance from 30 mph and Maximum Cruise Speed on Wet and Dry Pavement

13.18 Handling Safety in Steady State Yaw Response (Optional Test)

13.19 Handling Safety in Transient Yaw Response (Optional Test)