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ENERGY

FINAL REPORT

CONSERVATION

Evaluation and Recommendation of Electric and Hybrid Vehicle Performance Standards

for the:
United States
Energy Research and Development
Administration
Conservation Section
Washington, D.C. 20545

MASTER

by the:
Society of Automotive Engineers
400 Commonwealth Drive
Warrendale, Pa. 15096

U.S.-ERDA Contract No. EC-77-C-01-5053

SAE Identification No. R-29

30 September 1977

ENERGY RESEARCH AND
DEVELOPMENT ADMINISTRATION

Office of Conservation
Division of Transportation Energy Conservation

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1. OBJECTIVES

The Society of Automotive Engineers, Inc. (SAE) entered into a contract with the Energy Research and Development Administration (ERDA) to review and adjudicate electric and hybrid vehicle performance standards being developed by Arthur D. Little, Inc. (ADL) and General Research Corporation (GRC). Specifically, an SAE Task Force was organized to:

- Identify an acceptable set of performance standards based on the work of the two ERDA contractors.
- Identify and revise those performance standards which were found to be unacceptable.
- Identify the omission of important performance standards and suggest procedures to develop them.
- Provide the Task Force rationale for the recommendations presented above.

This report presents a summary of Task Force deliberations and recommendations.

2. INTRODUCTION

An SAE Task Force was assembled to pursue the objectives defined above. Members were selected who have had direct experience with the design or testing of electric and hybrid vehicles. Emphasis was placed on experience with performance analysis and measurements as well as with safety requirements and testing. These were considered to be the primary areas in which new quantitative requirements and specifications would be developed.

Some difficulties were encountered in forming a representative committee because of a possible conflict of interest between potential hardware suppliers and the U.S. Government. Although this problem was resolved satisfactorily, the formation of a Task Force was delayed significantly.

Task Force meetings were held with both ERDA contractors to review their recommendations and to interact with them during the preparation of their final reports. These meetings certainly were important to the Task Force, and we trust that these exchanges were also profitable to the ERDA contractors.

The Task Force met at the SAE National Headquarters in a working session to produce this document. Within the limited time which these voluntary members could commit to this activity, we believe that we have addressed the more critical issues surrounding the performance requirements for near-term private and commercial electric vehicles. The committee felt that it did not have sufficient experience with hybrid vehicles to produce separate performance standards for this vehicle class. Requirements for agricultural vehicles also were not developed.

The Task Force has concurred with both ERDA contractors that performance standards as opposed to design standards be promulgated in order that vehicle designers be provided with maximum latitude. In general, the recommended performance standards relate to overall vehicle operation and, we believe, are the simplest set of specifications consistent with defining vehicle maximum torque, power, and energy requirements. Requirements have been kept simple to avoid over-specifications and a conflict of requirements. The Task Force reviewed new classes of equipment required in an electric vehicle power train and a number of component performance specifications also were developed.

The performance specifications recommended by A. D. Little were similar to but somewhat more stringent than those recommended by GRC. It was interesting to compare the less demanding GRC performance standards to measured electric vehicle performance data provided by the contractors. Only one vehicle (Sundancer) was found to pass all of the performance requirements (acceleration, range, top speed, and fuel economy). Although several vehicles fell near the performance limits, most vehicles were rejected based upon either the acceleration or fuel economy requirements. The Task Force has judged that acceleration was limited principally by the power handling capability of the power control equipment and is probably not a fundamental limitation. The committee has elected to specify no energy efficiency requirements because of the limited data base available. The Task Force, therefore, believes that the recommended performance specifications which are considered to be the minimum requirements consistent with introducing new vehicles into existing urban traffic can be achieved by near-term electric vehicles.

The following section summarizes Task Force recommendations using the broad topical outline developed by GRC. Electric and hybrid vehicles generally are expected to have performance handling and safety characteristics similar to conventional vehicles and should be designed and built using applicable standard practices. Performance requirements are offered in areas where exceptions are necessary to accommodate the more limited characteristics of near-term electric vehicles.

3. REVIEW OF PERFORMANCE STANDARDS

In the following recommendations of the SAE Task Force, only state-of-the-art or "near-term" electric vehicle performance has been addressed. The following recommendations

apply to both private and commercial electric vehicles with the one exception that the minimum range for commercial vehicles is to be determined by tests using Schedule B (J227a) whereas private vehicles are to be tested on Schedule C.

In omitting discussion of performance requirements for "advanced vehicles," the SAE Task Force addressed what is understood to be ERDA's most urgent requirement; i. e., performance requirements for the first buy under P. L. 94-413. This law provides that advanced vehicle performance requirements be developed after vehicles of the first buy have been demonstrated.

In requiring that both private and commercial vehicles meet (with one exception) the same performance standards, the Task Force considered light urban commercial vehicles (under 4500 kg GVW) which are expected to operate in the same environment as private vehicles and therefore, are subject to the same requirements and constraints. Based on an analysis of present traffic patterns, the proposed vehicle performance requirements have already been degraded by the Task Force to what it feels are minimums for safe operation.

3.1 Standards for Utility

3.1.1 Vehicle Performance

Vehicle performance characteristics specified below are to be determined using procedures defined in SAE J227a. This standard practice specifies the ambient temperature range for tests. In addition, the Task Force recommends that the equipment be required to operate but not necessarily perform to these standards within ambient temperature ranges from -25° C (-13° F) to 50° C (122° F).

All vehicle performance tests called for in this section are to be run with the following specific electrical equipment in operation:

- wipers
- defroster (if electrical)
- running lights
- heater (if electrical)
- all blowers

Acceleration

We recommend that vehicles have a minimum acceleration capability of 0 - 50 kilometers/hour in 12 seconds when loaded to the manufacturer's recommended gross vehicle weight. This is judged to be a minimum requirement consistent with operating on urban streets. A vehicle capable of just achieving this acceleration level is not considered adequate for freeway operation.

Maximum Speed

Vehicles should be capable of achieving a speed of 88 kilometers/hour and sustaining that speed for at least five minutes. Although this peak speed is consistent with freeway operation, the intent of this performance requirement is to provide the vehicle with a performance margin for maneuvering on city streets.

Minimum Range

We recommend that private urban vehicles be capable of a minimum range of 50 kilometers operating under the SAE J227a "C" driving cycle, while light commercial vehicles should have a minimum range of 50 kilometers using J227a Schedule B. We do not recommend an additional specification on range at constant speed.

Gradeability

We recommend that vehicles be able to start in either forward or reverse on a 25% grade when the battery is near a full state of charge. Additionally, we recommend that the vehicle be required to ascend a 15% grade at 25 kilometers/hour for at least 30 seconds while maintaining allowable motor and controller temperatures.

Energy Consumption

Vehicle buyers historically have been given an opportunity to select from a spectrum of different vehicles and to make their own trade-offs between performance characteristics such as acceleration and fuel consumption to satisfy their personal requirements and tastes. Within reasonable limits, the committee believes the consumer should continue to be given this opportunity. The matter of setting reasonable bounds upon energy consumption demands an understanding of the practical limits of electric drivetrain design. Energy consumption data for electric vehicles are being accumulated, but the committee believes the present data base to be inadequate to establish energy consumption goals at this time.

Driveability/Controlability

Driveability relates to characteristics such as stumble, hesitate, flat spots, etc., experienced with ICE vehicles which are due to carburetion problems. While driveability as such is not a problem, electric vehicles have a unique speed control problem which might properly be called controlability.

Specification of speed control which would preclude the use of step controllers is not recommended. Demonstrations under the public law No. 94-413 should establish the acceptability of step controllers to the using population. The

Task Force believes that market acceptability will encourage designers to use continuous speed controllers.

Handling

Vehicle handling characteristics should be consistent with the state-of-the-art. A specific value for vehicle turning circle is not recommended. There is an established body of data relating turn-circle to vehicle wheel-base. We recommend that electric vehicles be designed to have turn-circle/wheel-base relationships typical of other vehicles of the same general size.

3.1.2 Payload

We recommend that no specifications be placed on the number of passengers or cargo carrying capacity of electric vehicles. This should be left up to the vehicle manufacturer based on what he feels will be most attractive in the marketplace.

The Task Force believes the performance requirements defined above are within the present state-of-the-art, albeit on the leading edge of the state-of-the-art.

In arriving at this conclusion, the Task Force considered the following data reported by NASA/Lewis:

	Range on Schedule "B"	Range on Schedule "C"	Task Force Recommended Range	Top Speed	Task Force Recommended Top Speed
Batronic	-	62.75 km	50 km	91.71 km/h	88 km/h
Ripp Electric	-	93.32 km	50 km	86.88 km/h	88 km/h
EVA	-	31.75 km	50 km	80.45 km/h	88 km/h
Jet Industries	-	33.95 km	50 km	70.79 km/h	88 km/h
Postal Jeep	51.49 km	-	50 km	48.27 km/h	88 km/h
Citicar	-	31.38 km	50 km	51.49 km/h	88 km/h
Lucas Limousine	-	77.88 km	50 km	82.86 km/h	88 km/h

The Copper Development Association (CDA) Town Car was tested on Schedule "D" and travelled 54.87 km with EV-106 batteries. All of the vehicles used this type of (golf car) battery except the Battronic, Postal Jeep, and Lucas Limousine, which used semi-industrial type batteries.

Thus, out of seven vehicles, four exceeded the suggested 50 km range on the SAE driving cycle (5 out of 8 if the CDA vehicle is included). The recommended top speed was achieved by two of the seven vehicles while two others reached over 90% of the recommended speed of 88 km/h.

3.1.3 Equipment Performance

In this section, utilization requirements for equipment peculiar to electric vehicles are addressed.

Battery Recharge Equipment

Equipment should be provided which will allow the vehicle propulsion battery to be charged from a fully discharged to a fully charged state in less than 12 hours. The charging equipment for private vehicles should use 120 volt AC power. It is recommended, but not required, that the charger be on board the private vehicle in order that it can be recharged from any available source of AC power. Commercial electric vehicles may use off-board 240 VAC powered chargers. The charger must simultaneously recharge the separate batteries that power the non-propulsion equipment of the electric vehicle.

State-of-Charge Indicator

All vehicles must be equipped with a state-of-charge indicator for the propulsion battery system. This meter should reflect the current state-of-the-art.

Equipment Temperature Sensors/Indicators

Designers must give consideration to warning devices which would forewarn of catastrophic failures of all of the major components of the vehicle propulsion system.

3.2 Standards for Durability

Design Life

Vehicles are intended to have an operational life of ten years or 160,000 kilometers. Power train components such as switches, controllers, and motors should be designed for this total life. Propulsion batteries are expected to be replaced during the operational life of the vehicle, but should be capable of 300 deep discharge cycles (cycles in which 80% of the energy of fully charged batteries is removed and replaced).

Maintainability/Repairability

Vehicle designers are expected to design the vehicle and its components for maximum ease of maintainability and repairability. No quantitative criteria can be specified. Because of the predominately urban environment in which the electric vehicle shall operate, it should comply with the requirements of FMVSS 215 and Part 581 -- the pair known as the "Bumper Standards".

3.3 Standards for Economy

One of the purposes of this program is to create vehicles which consume a minimum amount of energy. It is, therefore, the responsibility of the designer to

create components of the highest efficiency possible within reasonable economic bounds. Sufficient test data is not available to make possible a specification which is either meaningful or supportable. The Task Force, therefore, does not recommend specifying energy consumption; e.g. kWh/km, kg.

Life Cycle Costs

The lowest possible life cycle costs should be an objective.

3.4 Standards for Safety

As a general rule, we accept the recommendations of GRC and ADL that electric and hybrid vehicles comply with all applicable Federal laws and regulations. In particular, we were impressed with the logic and analysis used by GRC in their development of the recommended safety specifications. Like GRC, the Task Force also recommends some exceptions and additions to the existing standards. These are noted below:

FMVSS 102 & 103

TRANSMISSION BRAKING EFFECT; WINDSHIELD DEFROSTING AND DEFOGGING SYSTEMS

A test procedure should be developed which would be more appropriate for an electric vehicle.

FMVSS 109

TIRES

Tires built to comply with FMVSS 109 have a rated speed capability in excess of the near-term electric vehicles. It is desirable to provide standards for electric vehicle low rolling resistance tires that would satisfy safety requirements at lower achievable speeds.

FMVSS 124

ACCELERATOR CONTROL SYSTEMS

It is recommended that this standard should be amended to include electric controls:

- . A mechanical switch operated by the driver to physically open the circuit between the motor and battery.
- . Interlock -- such that the vehicle cannot be driven away while the battery charger is connected.

FMVSS 208

OCCUPANT CRASH PROTECTION

During any crash test sequence and the dynamic roll-over test, the batteries shall always be extant of the passenger compartment.

FMVSS 301

FUEL SYSTEM INTEGRITY

This would apply fully to any electric or hybrid vehicle in which the fuel or electrolyte is a liquid that is a fatality-producing mechanism (flammable, explosive, etc.). If not, the spillage requirements would be limited to the electrolyte containment in a static roll-over test.

There are other safety areas unique to electric and hybrid vehicles, not presently covered by existing FMVSS specifications. GRC indicated concerns with areas not covered by existing FMVSS. We have accepted their recommendations and present them below, with some modifications:

- . Shock Hazard

The main propulsion battery should be electrically isolated from the vehicle chassis to reduce the chance of an occupant or service-person receiving an electrical shock if a battery terminal is touched.

- . Explosive Gas Hazard

Lead-acid batteries emit hydrogen and oxygen when they are charged or during discharge if one or more cells has been reversed. Adequate ventilation must be provided to ensure that potentially explosive mixtures do not accumulate. Venting should not be through the passenger compartment. Additionally, the batteries must have explosive-proof caps, a standard item for automotive batteries.

- Motor Runaway

Solid state controllers sometimes fail in a short-circuit mode. This could have disastrous consequences if provision is not made for disconnecting the propulsion battery. Whether manual or automatic, this feature must be provided. This device must also be able to be checked by the driver on a routine basis. For vehicles with a clutch, motor run-away presents less of a safety hazard, but a disconnect mechanism should still be provided.

- Battery Shorting

Battery short circuits can create high temperatures, explosions, and fire hazards. Possible failure mechanisms are control circuit failures, electrical shorts caused by external objects during maintenance, and crashes that crush the batteries.

Although objective performance regulations are not presently available for the following safety criteria, some evaluation of these should be emphasized for electric vehicles which will be used primarily in an urban traffic environment.

- Pedestrian Impact Protection
- Vision-Direct (front & sides)
- Vision-Indirect (rear)
- Handling degradation due to extremely stiff suspension ride rates.

3.5 Standards for Amenity

Most of the characteristics listed under this heading concern the aesthetics of the vehicle. Their evaluation is highly subjective, yet very crucial to the commercial acceptability of a private motor vehicle. Some of the following characteristics can be objectively measured (appropriate SAE Recommended Practices are noted) but few published performance limits are available -- acknowledging that the automotive industry has proprietary specifications established through long experience with marketing motor vehicles. The characteristics are:

- Accessories

Non-standard items which ought to be available

- Comfort

Seating and driving position (SAE Standard J879b, Motor Vehicle Seating Systems), ride, and noise (SAE Standard J986b and SAE Recommended Practice J1030 plus applicable EPA standards). We suggest an 80 dbA maximum limit.

- Convenience

Ease of seat access and central ergonomics (SAE Standards J287, J941d, and J1050), instrument legibility, luggage and spare tire access

- Environmental Control

Heating, cooling, fresh air, and odors

- Steering and Braking Effort

Brake pedal effort is specified in FMVSS 105-75. We suggest a maximum parking steering effort (vehicle not moving) of 50 lbs. rim pull when the vehicle is on a glossy floor.

3.6 Standards for Pleasureability

This is not an appropriate concern of the purchase specification.

3.7 Standards for Ecological Compatibility

We have moved the item "Electromagnetic Interference" (EMI) from Section 3.5 to this section. It should be noted that EMI may effect radios and other electronic apparatus in the vicinity of the electric vehicle. Test procedures for vehicle component electromagnetic susceptibility are presented in SAE Recommended Practice J1113.

Aside from ecological specifications limiting the undesirable vapor, solid, and EMI emission from electric vehicles, we see no practical way, at this time, to limit the electric vehicle impact on the consumption of energy and use or re-use of materials other than to specify its propulsion efficiency when a more adequate data base becomes available.

3.8 Standards for Marketability

None of the items listed by GRC in this category are susceptible to specifications, but an item suggested by ADL is:

Documentation

Owner's manuals, service (maintenance) manuals, and Parts lists must be provided and updated.

4. CONCLUSIONS

Better vehicle performance specifications can be developed as more reliable test data and field experience becomes available. In particular, safety-related vehicle component performance requirements should be defined after crash tests are run with this class of vehicle. The Task Force recommends that ERDA identify the development of vehicle performance requirements as a specific task which is carried forward concurrently with the electric and hybrid vehicle test and demonstration program.

Electric Vehicle Test Procedure—SAE J227a

**SAE Recommended Practice
Last Revised February 1976**

**THIS IS A PREPRINT AND WILL
APPEAR IN THE NEXT EDITION
OF THE SAE HANDBOOK**

Society of Automotive Engineers, Inc.
400 COMMONWEALTH DRIVE, WARRENDALE, PA. 15096

PREPRINT

Report of Electric Vehicle Technical Committee approved March 1971 and last revised February 1976.

1. Purpose and Scope—This SAE recommended practice establishes uniform procedures for testing electric battery powered vehicles which are capable of being operated on public and private roads. It is the intent of these recommended practices to provide standard tests which will allow various performance characteristics of electric vehicles to be cross-compared on a common basis in specifications, technical papers, and engineering discussions. The tests concern attributes of the total vehicle system rather than those of its subsystems and components. Tests of components such as batteries are the subject of separate procedures.

The road tests specified in this standard practice are recommended for use whenever possible particularly to establish vehicle performance specifications. The dynamometer procedures are included primarily to facilitate development testing.

Section 2 provides definitions of terminology used in this document. Section 3 specifies test conditions and instrumentation which are to be used for all the tests specified in this recommended practice while Section 4 identifies the data which are to be recorded for all tests. The specific tests covered by this document are:

- Range at Steady Speed (Section 5)
- Vehicle Range When Operated In A Selected Driving Pattern (Section 6)
- Acceleration Characteristics On A Level Road (Section 7)
- Gradeability Limit (Section 8)
- Gradeability at Speed (Section 9)
- Vehicle Road Energy Consumption (Section 10)
- Vehicle Energy Economy (Section 11)
- Deceleration (Section 12)

2. Terminology

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

2.3 Gradeability—The maximum percent grade which the vehicle can traverse for a specified time at specified speed. The gradeability limit is the grade upon which the vehicle can just move forward.

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.

2.5 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.

2.6 Tractive Force—The force available from the driving wheels at the driving wheel ground interface.

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).

2.8 Maximum Cruise Speed—The highest vehicle speed sustainable for at least one 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.

3. Test Conditions and Instrumentation Common To All Tests—The following conditions shall apply to all tests defined in this recommended practice unless otherwise stated in specific test procedures.

3.1 Condition of Vehicle

3.1.1 Vehicle shall be tested in its normal configuration with normal appendages (mirrors, bumpers, hub caps, etc.).

3.1.2 The vehicle shall be tested at manufacturer's rated gross vehicle weight.

3.1.3 Manufacturer's recommended tires shall be used. Tire pressures shall not exceed pressures recommended by Tire and Rim Association (TRA). Tire tread shall not be worn to the point where the tread wear indicators are exposed.

3.1.4 Normal manufacturer's recommended lubricants shall be employed.

3.1.5 The vehicle shall be stored for a minimum 8 h soak at ambient temperature (Section 3.3.1.1) before tests which start with a fully charged battery.

3.2 Condition of Battery

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

3.2.2 A minimum 8 h soak period at ambient temperature (Section 3.3.1.1) shall be allowed after completion of charging and before starting tests initiated with fully charged battery.

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

3.2.4 For tests requiring an N% discharged battery at the start (for example, gradeability tests), the required initial state-of-charge will be established as follows. A Range at Steady Speed test (Section 5) shall be performed at recommended maximum cruise speed, and the end-point time and watt-hours consumed to the end-point of range determined. To achieve N% discharge of a fully charged battery, the battery will be discharged for N% of the end-point time either by driving the vehicle at recommended maximum cruise speed or by discharging the battery through a load at an equivalent constant power. Tests conducted with the battery partially discharged at the start must be initiated no longer than 10 min after the desired initial state-of-discharge is reached.

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

3.3 Environmental Conditions

3.3.1 GENERAL

3.3.1.1 Temperature during vehicle and battery ambient soak period shall be within the range of 16°–32°C (60°–90°F). Ambient temperature during road testing shall be in the range of 5°–32°C (40°–90°F).

3.3.2 ROAD TESTS

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

3.3.2.2 The recorded wind speed at the test site during test shall not exceed 16 km/h (10 mph).

3.3.3 DYNAMOMETER TESTS

3.3.3.1 Dynamometer load must be programmable at various vehicle speeds to simulate vehicle road load versus speed characteristics.

3.3.3.2 Dynamometer road load power settings shall be made using either of the following procedures. Data from the coast-down tests described in Section 10 which establish the power required at various vehicle speeds to overcome aerodynamic drag and rolling resistance may be directly used to program the power absorbed by the dynamometer. Alternatively the dynamometer road load points can be set to require the same power output from the battery as is required to propel the vehicle at constant speed on a level roadway. Battery power required to maintain various steady road speeds shall be measured using the vehicle testing procedures described in Section 5 of this document.

3.3.3.3 Dynamometer flywheel shall be engaged with the nearest available inertial weight which equals or exceeds the rated gross vehicle weight.

3.4 Test Instrumentation—This section provides a list of instruments which are required to perform the tests specified in this recommended practice. The overall error in recording or indicating instruments shall be no worse than ±2% 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.

3.4.1 GENERAL INSTRUMENTATION—The following classes of instruments are required for the purpose of tests outlined in this procedure.

- DC watt-hour meter or watt-time recorder
- Vehicle speed versus time recorder
- Distance versus time recorder
- Tire pressure gauge
- Ambient temperature versus time indicator
- DC watt meter
- Battery temperature indicator
- Electrolyte hydrometer (for vehicles with lead-acid batteries)
- AC kilowatt-hour meter

3.4.2 ROAD TESTS

- Wind speed and direction measurement versus time
- Means for determining grades of test route segments
- Fifth wheel for measuring vehicle speed and distance

4. Data to be Recorded for all Tests

4.1 General

4.1.1 Vehicle Identification.

4.1.2 Overall maximum dimensions (including projected frontal area).

4.1.3 Weight: curb weight and test weight to within ±2%.

4.1.4 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, description of the last discharge and recharge processes, and a brief description of known adverse usage conditions.

- State of initial charge using the definition of percent charge presented in Sections 3.2.3 and 3.2.4. Where meaningful, other parameters such as open circuit voltage, electrolyte specific gravity, etc., shall also be stated.

- Watt-hours discharged during test.

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

4.1.3 Motor type and rating.

4.1.6 Overall drive train ratios available, and those used during test, plus vehicle speeds at shift points if manual transmission.

4.1.7 Tires: manufacturer, design, size, rolling radius as specified by tire manufacturer, and pressure at start and end of test.

4.1.8 Power consumption of individual accessories, and times when each accessory was on during the test.

4.1.9 ENVIRONMENTAL CONDITIONS:

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

4.1.10 Running surface (road surface or dynamometer wheels).

4.1.11 Description of test route or dynamometer load program—road class, road surface type and condition (Table 9 of SAE J688), and lengths and grades of test route.

4.1.12 Date and starting and ending times of test.

4.1.13 List of all instrumentation used in test (manufacturer, model no., serial no.) and their last calibration date.

4.1.14 Any deviation from test procedure and reason for deviation.

4.2 Road Tests

4.2.1 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 in each direction. The range of test results and the number of test runs also shall be reported.

4.3 Dynamometer Tests

4.3.1 Description of dynamometer used (including drum or roll diameter and number of tire contact points).

4.3.2 Road load set points.

4.3.3 Equivalent inertial weight used.

4.3.4 Vehicle speed from dynamometer roll.

5. Range at Steady Speed

5.1 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 steady speed.

5.2 Test Procedure—These road or dynamometer tests are to be conducted subject to the test conditions and data requirements described in Sections 3 and 4. Range tests are to be conducted at a minimum of three different test speeds including one test at the recommended maximum cruise speed of the vehicle. Individual tests shall be started with the vehicle propulsion battery in a full state of charge.

5.2.1 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 test shall be continued without interruption at the preselected speed which is to be maintained to within $\pm 3\%$ until the vehicle reaches its end of range as defined in Section 5.3. The vehicle range shall be determined as the average of several 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.

5.2.2 DYNAMOMETER TESTS—The vehicle shall be brought to the preselected test speed under its own power and operated without interruption at within $\pm 5\%$ of this speed until the end of range is reached as defined in Section 5.3. Dynamometer test conditions are defined in Section 3.3.3. Range shall be determined as the average of several tests and the reported speed shall be the average speed maintained during the testing.

5.3 Definition of End of Range—The end of driving range is reached when the vehicle speed falls below 95% 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 range to some characteristic of the battery such as terminal voltage under load.

5.4 Special Data Recording—In addition to recording the data specified in Section 4 the following special data shall be reported.

5.4.1 The test data shall be plotted as a curve showing range as a function of vehicle speed. The actual test points shall be indicated on this curve. When reporting these data, it shall be specified whether they are based upon road test or dynamometer test results.

5.4.2 The factor(s) involved in determining the end of range as defined in Section 5.3 shall be reported.

Vehicle Speed

FIG. 1—VEHICLE TEST CYCLE

TABLE 1—TEST SCHEDULE FOR REPEATABLE DRIVING PATTERN

Schedule	A	B	C	D
V	16 $\pm$ 1.5 km/h (10 $\pm$ 1 mph)	32 $\pm$ 1.5 km/h (20 $\pm$ 1 mph)	48 $\pm$ 1.5 km/h (30 $\pm$ 1 mph)	72 $\pm$ 1.5 km/h (45 $\pm$ 1 mph)
t _a	4 $\pm$ 1	19 $\pm$ 1	18 $\pm$ 2	28 $\pm$ 2
t _{cr}	0	19 $\pm$ 1	20 $\pm$ 1	50 $\pm$ 2
t _{co}	2 $\pm$ 1	4 $\pm$ 1	8 $\pm$ 1	10 $\pm$ 1
t _b	3 $\pm$ 1	5 $\pm$ 1	9 $\pm$ 1	9 $\pm$ 1
t _i	30 $\pm$ 2	25 $\pm$ 2	25 $\pm$ 2	25 $\pm$ 2
T	39 $\pm$ 2	72 $\pm$ 2	80 $\pm$ 2	122 $\pm$ 2

NOTE: All times shown are in seconds.

6. Vehicle Range When Operated In A Selected Driving Pattern

6.1 Purpose of Test—The purpose of this test is to determine the maximum range traveled and 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.

6.2 Definition of Test Cycles—Four test cycles are defined to allow the vehicle to be tested under conditions which best match its intended use. The four test cycles all have the characteristics shown in Fig. 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 four test cycles are presented in Table 1.

6.2.1 DRIVING SCHEDULE A—Schedule A is characterized by a peak speed of 16 km/h (10 mph) and is intended for use in testing a vehicle designed for use on a fixed route with high frequency stop and go operation (for example, residential postal delivery van, milk truck, etc.).

6.2.2 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, etc.).

6.2.3 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.).

6.2.4 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.).

6.3 Test Procedures—The road or dynamometer tests defined in this procedure are to be conducted subject to the test conditions and data requirements of Sections 3 and 4. The tests are to be started with the battery fully charged using the vehicle manufacturer's standard procedures.

6.3.1 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 6.3.3. The vehicle

FIG. 2—ACCELERATION CHARACTERISTICS

range shall be determined as the average of at least three tests 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.

6.3.2 DYNAMOMETER TESTS—The test vehicle shall be operated repeatedly and without interruption over the selected driving schedule on a dynamometer until it reaches its end of range as defined in Section 6.3.3. Dynamometer test conditions are defined in Section 3.3.3.

6.3.3 END OF RANGE—The end of 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.

6.4 Special Data Recording—In addition to recording the data specified in Section 4 the following special data shall be reported.

6.4.1 The range achieved, the number of test cycles successfully completed, and the test schedule used shall be recorded for each range test. The range reported shall be the average range achieved over at least three tests. The number of tests and the spread of the data also shall be reported. When reporting these data, it shall be specified whether they are based upon road test or dynamometer test results.

6.4.2 The factor used to define the end of range in Section 6.3.3 shall be identified and reported.

6.4.3 When dynamometer tests are run the road load set points used in the dynamometer shall be specified.

7. Acceleration Characteristics On A Level Road

7.1 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.

7.2 Test Procedure—The road and dynamometer tests defined in this section are to be conducted subject to the test conditions, instrumentation, and data recording requirements of Sections 3 and 4.

7.3 Road Test Procedure

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

7.3.2 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.

7.3.3 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 3.2.5. The time interval from the start of coast-down to the beginning of the next successive acceleration run at each battery state-of-charge shall not exceed five minutes.

7.4 Dynamometer Tests—Dynamometer test conditions are defined in Section 3.3.3. Vehicle speed shall be determined for these tests from measurements of the dynamometer drum or roller speed.

7.5 Special Data Recording—In addition to recording the data specified in Section 4, the following special data shall be reported.

7.5.1 The vehicle's acceleration characteristics shall be plotted as speed versus time for each of the initial states-of-charge as illustrated in Fig. 2. For each state-of-charge, the data to be plotted shall be the average results of at least two runs for that initial state-of-charge. When reporting these data, it shall be specified whether they are based upon road test or dynamometer test results.

8. Gradeability Limit

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

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

8.2.1 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 1.5 km/h (1 mph).

8.2.2 The tractive force shall be determined for various battery states-of-charge where the latter are defined in Section 3.2.5.

8.2.3 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.

8.3 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)

8.4 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.

9. Gradeability At Speed

9.1 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 this vehicle capability is to be brought out in these tests. Two alternate procedures are described. An analytical method using data collected in Section 7, "Acceleration Characteristics On A Level Road" is described along with a direct dynamometer procedure.

9.2 Analytical Method

9.2.1 Using the speed-time data from the road tests of Section 7, the vehicle's acceleration characteristics shall be plotted as in Fig. 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 n th time interval

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

when the vehicle has reached the average speed,

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

The data derived from these calculations shall be 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 Fig. 4. If the test vehicle is equipped with a recording accelerometer as well as speedometer during the test of Section 7, the information of Fig. 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:

$$\text{Percent Gradeability at Speed} = 100 \tan (\sin^{-1} 0.0283a)$$

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

FIG. 3—VEHICLE SPEED VERSUS TIME DURING ACCELERATION

FIG. 4—VEHICLE MAXIMUM ACCELERATION VERSUS VEHICLE SPEED

The constant 0.0285 in this equation becomes 0.0435 when the vehicle's acceleration is determined in English units of mph s.

9.3 Dynamometer Tests—A chassis dynamometer also can be used to determine gradeability at speed providing that the total road power loss of the vehicle has been established for various vehicle speeds using the procedure of Section 10.

9.3.1 DYNAMOMETER TEST PROCEDURE—Dynamometer tests of vehicle gradeability at speed are to be made for a number of different initial battery states-of-charge. Vehicle and dynamometer test conditions are those presented in Section 3.

9.3.1.1 With a preselected dynamometer load the vehicle shall be accelerated to a stabilized balance speed which must be maintained for a minimum period of 20 s. Speed variation during the 20 s test interval should not exceed five percent.

9.3.1.2 The dynamometer power consumption shall be determined at various speeds and used to calculate gradeability at speed.

9.3.2 DYNAMOMETER DATA PROCESSING—The percent gradeability at speed for the test vehicle shall be calculated from the dynamometer test data and the road load data of Section 10 using the following relationship:

$$\text{Percent Gradeability at Speed} = 100 \tan \left[\sin^{-1} \left(\frac{367.2 (p - P_0)}{WV} \right) \right]$$

where p = power delivered to the dynamometer at test speed, kw (hp)

P_0 = road load power consumed by the vehicle at test speed (Section 10), kw (hp)

FIG. 5—VEHICLE SPEED VERSUS TIME DURING COASTING

V = vehicle test speed, km/h (mph)

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

The constant in the above equation is 375 when English units are used.

9.4 Special Data Recording

9.4.1 The calculated percent gradeability of the vehicle shall be recorded for each test speed and for the three battery initial states-of-charge specified in Section 3.2.5.

9.4.2 When reporting these gradeability data, it shall be specified whether they are based upon road test or dynamometer test results.

10. Vehicle Road Energy Consumption

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

10.2 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:

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

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

10.2.3 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.

10.2.4 During the coast-down tests, the power train loads which are coupled to the wheels shall be minimized or removed. If the vehicle has a transmission then the motor shall be mechanically isolated from the armature and field of the motor shall be electrically open circuited. A correction factor described in paragraph 10.4.4 shall be used to compensate for those power train loads which cannot be removed easily.

10.3 Data To Be Recorded

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

10.3.2 In addition to the general information to be recorded which is specified in Section 3, any special modifications of the vehicle which were made to minimize power train loads during the coast-down test as described in the previous paragraph shall be recorded.

10.4 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 curve shall be plotted as shown in Fig. 5.

10.4.1 VEHICLE ROAD LOAD POWER—The vehicle propulsion power required to overcome aerodynamic and rolling resistance is to be determined from Fig. 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

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

then shall be determined from the following relationship:

FIG. 6—ROAD POWER VERSUS VEHICLE SPEED

FIG. 7—ROAD ENERGY CONSUMPTION VERSUS VEHICLE SPEED

$$P_n = 3.86 \times 10^{-3} W \frac{(V_{n-1}^2 - V_n^2)}{(t_n - t_{n-1})}, \text{ kw}$$

where W = manufacturer's rated gross vehicle 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^{-3} and vehicle weight is in pounds, speed is in miles per hour and time is in seconds.

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

10.4.2 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 Fig. 5.

Again using the vehicle speed, V_n , at successive time intervals, t_n , the road energy consumed at the average speed:

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

shall be determined using the following equation:

$$E_n = 7.72 \times 10^{-3} W \frac{(V_n^2 - V_{n-1}^2)}{(t_n - t_{n-1})}, \frac{\text{kw h}}{\text{km}}$$

where W = manufacturer's rated gross vehicle 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^{-3} 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 plotted as illustrated in Fig. 7.

10.4.3 ALTERNATE PROCEDURES—The equations of paragraphs 10.4.1 and 10.4.2 use speed changes over fixed time intervals to determine an average deceleration rate. The calculations therefore yield the average values of energy and power dissipated during each selected time interval. The average dissipated energy and power therefore were plotted in Figs. 6 and 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 can be determined using appropriate equations to produce the relationships illustrated in these figures.

10.4.4 CORRECTION FOR POWER TRAIN LOADS—The values determined using this procedure are to be the energy and power 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 10.4.1 and 10.4.2 to compensate for those power train loads which could not be eliminated during the coast-down tests. Specifically the windage and friction losses in the motor and drive line 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 drive line then are to be used to relate component speeds to vehicle speed and the energy and power dissipated in the drive line 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 Figs. 6 and 7.

11. Vehicle Energy Economy

11.1 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.

11.2 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 defined as the vehicle range in various operating modes divided by the AC energy required to return the battery to its original state-of-charge. The vehicle energy economy therefore is defined as follows:

$$\text{Energy Economy} = \frac{\text{Range in prescribed driving mode}}{\text{AC energy required to recharge battery, km kWh (miles kWh)}}$$

11.3 Test Procedure—Tests for determining vehicle range at steady speed and vehicle range over a definite repeated driving cycle have been defined in Sections 5 and 6, respectively. Either of these range tests can be used to establish values for vehicle energy economy.

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

11.3.2 A watt-hour meter shall be installed across the AC 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.

11.4 Data Recording—The range of the vehicle at steady speed or its range over a repeated driving cycle is to be divided by the AC 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.

In the case of the continuous speed driving mode, the energy economy data can be presented in the form of a curve per Fig. 8.

In the case of the repeatable driving pattern, the results should be presented in tabular form for the driving modes tested.

12. Deceleration

12.1 The vehicle shall be subjected to the same braking tests as other road vehicles and existing SAE standard practices shall apply.

FIG. 8—ENERGY ECONOMY PLOT

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