ELECTRIC VEHICLE TEST PROCEDURE—SAE J227a SAE Recommended Practice

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 X% 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 X% discharge of a fully charged battery, the battery will be discharged for X% 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).

4.1.5 Motor type and rating.

4.1.6 Overall drive train ratio(s) 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 wheel).

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 ±5% 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

±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.

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.

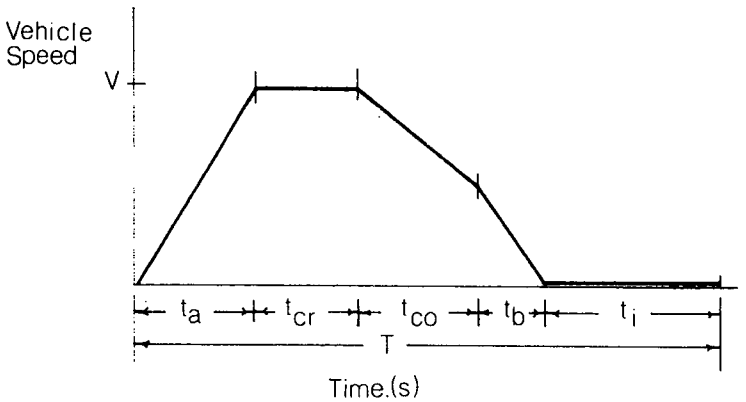

FIG. 1—VEHICLE TEST CYCLE

TABLE 1—TEST SCHEDULE FOR REPEATABLE DRIVING PATTERN

Schedule	A	B	C	D
V	16 ± 1.5 km/h (10 ± 1 mph)	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	4 ± 1	19 ± 1	18 ± 2	28 ± 2
t_{cr}	0	19 ± 1	20 ± 1	50 ± 2
t_{co}	2 ± 1	4 ± 1	8 ± 1	10 ± 1
t_b	3 ± 1	5 ± 1	9 ± 1	9 ± 1
t_i	30 ± 2	25 ± 2	25 ± 2	25 ± 2
T	39 ± 2	72 ± 2	80 ± 2	122 ± 2

NOTE: All times shown are in seconds.

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 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.

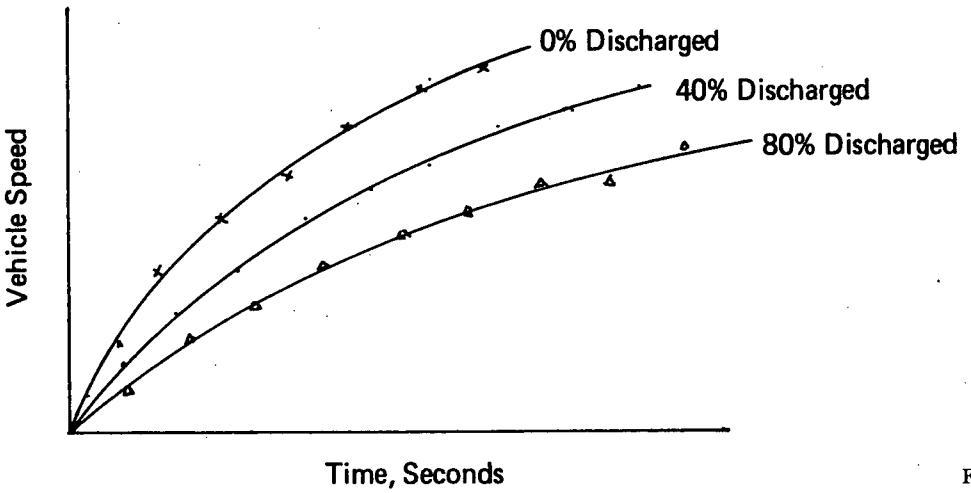

FIG. 2—ACCELERATION CHARACTERISTICS

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 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,

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

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:

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

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.

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.

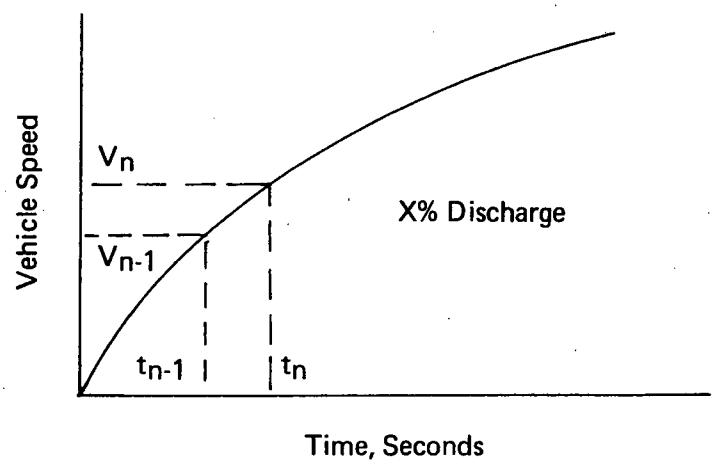

FIG. 3—VEHICLE SPEED VERSUS TIME DURING ACCELERATION

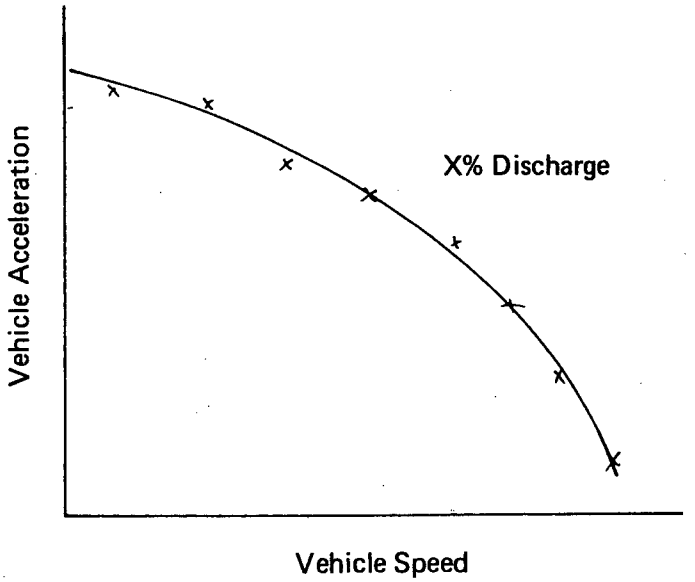

FIG. 4—VEHICLE MAXIMUM ACCELERATION VERSUS VEHICLE SPEED