

Off-Road Vehicle Mobility Evaluation — SAE J939



SAE Recommended Practice
Handbook Supplement

Off-Road Vehicle Mobility Evaluation — SAE J939

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1. INTRODUCTION

Off-road mobility is an important requirement for many types of automotive vehicles, such as those with military applications. The term "off-road mobility," as it pertains to this practice, is defined as a vehicle's ability to move itself and cargo cross-country in a manner that permits timely accomplishment of missions within the limits of its design function. If this characteristic is to be assured, test procedures must be established which adequately measure the performance characteristics that contribute to off-road mobility. Such tests are described in this report.

The tests and test procedures described attempt to indicate the major elements comprising an evaluation of off-road performance. In the event that the evaluation of a limited number of performance characteristics is desired, the appropriate test procedures can be utilized without reducing their utility.

2. OBJECTIVE

The purpose of this recommended practice is to provide: a uniform procedure for evaluating off-road mobility of self-propelled vehicles, and criteria for defining design requirements.

3. SCOPE

This practice emphasizes those qualitative and quantitative evaluations essential in determining a vehicle's ability to meet demands placed on it by off-road environments. It considers the major factors that directly influence mobility performance.

4. QUANTITATIVE TESTS

The test procedure shall minimize all effects except the mobility characteristics of a vehicle.

4.1 GENERAL - Quantitative tests entail the acquisition of vehicle performance data for vehicles operating in off-road conditions. Sufficient vehicle and soil measurements will be taken to permit the following determinations:

4.1.1 Vehicle ability to meet the demands of an off-road environment, as reflected by changes in performance relative to hard surface performance.

4.1.2 The motion resistance imposed on a vehicle by soft soil or other obstacles.

4.1.3 Effectiveness of the propulsion members in utilizing the power available to them, as indicated by the drawbar pull versus slip relationship.

4.2 VEHICLE MEASUREMENTS - The following measurements will be taken in such manner that determinations 4.1.1, 4.1.2, and 4.1.3 can be made:

- (a) Drawbar-pull.
- (b) Output shaft torques and speeds.
- (c) Vehicle speed.
- (d) Vehicle sinkage.
- (e) Vehicle trim.
- (f) Resistance to towing.
- (g) Fuel consumption.

A description of each measurement is contained in Appendices A-G.

This SAE Recommended Practice is oriented toward vehicles having military applications, and, as such the procedures for specific tests have been influenced by those utilized for evaluating military vehicles. Examples of these are drawbar pull, resistance to towing, and fuel consumption tests. Existing SAE test codes J872, J873 and J893 can be substituted for these where applicable, provided all required data are obtained. Some deviations in the existing test codes may be required to meet specific test objectives or test conditions. This would be acceptable providing sound engineering principles are applied.

5. GENERAL OBSERVATIONAL TEST

These tests consist of a series of operations over a variety of difficult but representative operating environments on which a minimum of measurements are required. The tests are primarily comparative in nature, allowing the mobility characteristics of two or more vehicles to be evaluated. To make the comparative tests of greatest use, one of the vehicles participating in the test should be a standard vehicle of the same weight class as the vehicle or vehicles being evaluated. The performance of the standard vehicle will then serve as a yardstick since the qualified observer will be able to establish the difficulty of the course on the basis of the performance of the standard vehicle.

Although the performance measurements may be kept at a minimum to include, for example, only average speed, number of immobilizations, and fuel economy, the operational test should not degenerate into a process of merely observing how a vehicle reacts to the impact of the off-road environment. In general, a characteristic should be measured when the measurement is reasonably simple to make - such as turning radius. However, when a measurement is very complicated, such as determination of vehicle stability, the evaluation should be restricted to the observation of the relative performance of the test and reference vehicles.

5.1 TERRAIN CONDITIONS - The terrain of the test area should be analogous to that which the vehicle will encounter in fulfilling its design function in the field. Where appropriate, level and hilly terrain, natural obstacles, sand, mud, swamps, snow, and inland waterways should be included in the test course. Operation over disturbed and undisturbed soil should be included where surface conditions change with traffic.

The operation test should be conducted on trails or strips of representative terrain. The length of trail or strip should be long enough to include as many of the surface conditions as practical in a given area. The width of the strip should be wide enough so that each vehicle being tested can make at least one pass over an undisturbed surface.

5.2 TEST PROCEDURE -

5.2.1 The basis of performance comparison should be between vehicles of similar mission assignment and of the same approximate size or payload capacity. Secondary comparisons can be made between the test vehicle and vehicles which may constitute a given operational unit.

5.2.2 The control vehicle used as a basis for performance

comparison should have a performance sufficiently familiar to the observer to have general significance.

5.2.3 The tests should bring into use as many vehicle characteristics as possible. That is, test areas should not be selected that demonstrate one characteristic favorably but void conditions that would demonstrate an unfavorable characteristic.

5.2.4 All vehicles should be equipped with standard components. The evaluation of special components should be accomplished through separate tests.

5.2.5 The vehicles shall be tested carrying the rated payload. If test conditions or other considerations call for testing at other than the rated payload, the loads should be changed proportionately.

5.2.6 All vehicles should be in a similar mechanical condition.

5.2.7 The operators should be completely familiar with the operating characteristics of the vehicle. The effect of a single operator may be minimized by rotation of test and reference vehicle operators during the progress of the test.

5.2.8 The number of passes through the test strips should be sufficient to determine:

- (a) The average ability of a vehicle to negotiate the terrain.
- (b) Significant performance differences between vehicles.

5.3 PERFORMANCE EVALUATION - Because the evaluation is basically qualitative, continual observation of all vehicles throughout the test course is necessary. Considerations in the evaluation should be:

- (a) Timeliness of course completion, that is, average speed.
- (b) Condition of vehicle and cargo on arrival.
- (c) The ease or difficulty with which the course is negotiated by each vehicle.
- (d) The number and cause of immobilizations.

6. TERRAIN DESCRIPTION

6.1 INTRODUCTION - Tests involving performance rating, whether through direct measurements or observation, must incorporate a description of the test terrain in sufficient detail to be of value. It is necessary to classify terrain by means of a standardized description in order to convey to others the conditions under which the test is conducted. Qualitative descriptions have proved themselves to be virtually useless since they can at best describe a general category

of conditions. It is necessary that terrain conditions be described by such factors as: soil strength, average slope conditions, overall geometric profile including ditches, and a pedological soil classification system such as that used by the United States Department of Agriculture.

6.2 GENERAL - For the purposes of off-road vehicle evaluations, terrain description can be divided into two groups: those characteristics which are stable over a long period of time, and those characteristics which are capable of rapid change. Terrain characteristics which appear in the non-changing group are:

- (a) Soil classification by the USDA Pedological System.
- (b) General ground profile (geometric).
- (c) Atterberg limits.

Terrain characteristics which are subject to change and therefore must be measured during the test period reflect soil strength, structure, and moisture content. The characteristics in this group are:

- (a) Land Locomotion Laboratory Soil Strength Parameters: (k_c , k_ϕ , n , c , ϕ , K).
- (b) Cone Index and Remolding Index.
- (c) Cohesion and angle of internal friction.
- (d) Moisture content.
- (e) Bulk density.

A description of each test, instrumentation and procedures for obtaining the measurement and classification of the terrain characteristics listed above can be found in Appendices H-N. The triaxial test is described in Appendix L but is highly specialized and should be performed by a recognized test agency or organization with the necessary equipment and capability. The description of the test, equipment, and procedure were provided in the interest of completeness.

6.2.3 COMPLETENESS OF TERRAIN DESCRIPTION - The optimum terrain description for an area where vehicle testing is to be performed would include all of the measurements and classifications mentioned in the previous section. In practice, the optimum description is only recommended for test sites which are, for all practical purposes, permanent sites. A permanent site can be interpreted in this case as a site where testing will continue for a period that justifies the expenditure of the time and money required to conduct each test. Tables 1 and 2 list what are considered the minimum soil measurements and classifications for quantitative-type and observational-type vehicle tests.

Table 1 - Quantitative-Type Tests

1. USDA soil classification: Texture, soil profile, vegetation.
2. Land Locomotion Laboratory soil strength parameters: c , ϕ , vertical load-deformation curves.
3. Cone Index and Remolding Index.
4. Moisture content.
5. Bulk density.
6. Geometric ground profile.

Table 2 - Observational-Type Tests

1. USDA soil classification: Texture, soil profile, vegetation.
2. Cone Index and Remolding Index (level terrain).
3. Ground profile (geometric).
4. Bulk density.
5. Moisture content.

APPENDIX A

DRAWBAR PULL

1. INTRODUCTION

Drawbar pull is a basic measure of vehicle performance either on or off-the-road. It is a conveniently obtained quantity essential to a vehicle comparison or evaluation program. Drawbar pull is determined by similar procedures for either tracked or wheeled vehicles.

2. DEFINITION

Drawbar pull is defined as the available tractive effort in excess of that necessary to propel the vehicle at a given constant speed on a level surface. It is a measure of the force available to accelerate the vehicle, climb grades, and pull towed loads.

3. PURPOSE

The purpose of determining drawbar pull is to establish vehicle performance for evaluation or comparison purposes.

4. THEORETICAL BACKGROUND

4.1 HARD SURFACE TESTS -

4.1.1 Hard surface tests are conducted on level pavement to determine the overall efficiency of the vehicle. Efficiency is taken as the ratio of measured drawbar pull and theoretical (rim pull, sprocket or wheel) drawbar pull. The efficiency is a measure of losses which include internal suspension frictional losses, external rolling resistance and, at higher speeds, aerodynamic drag. The measured drawbar pull is limited by the powerplant, transmission, suspension efficiency, and the traction that the wheels or tracks can develop on a given surface. Theoretical drawbar pull may be computed from data supplied by the vehicle manufacturer and assumes no traction limitation. Required data include the engine torque curve, gear ratios, and efficiencies in the various drive line components, and the rolling radius of the tire or pitch radius of the drive sprocket. The measured drawbar pull is established from the average of several tests.

On the hard surface tests, the test vehicle is operated throughout its range of gear ratios and at small speed increments to provide data for the drawbar horsepower versus speed curves. Drawbar load can be provided by any convenient system. Experience has shown that a dynamometer vehicle is the most useful loading device. A dynamometer vehicle should be sufficiently large to assure that the test vehicle can achieve 100% slip and should have adequate space for instrumentation and test personnel. However, a dynamometer vehicle is not essential to a drawbar test. It is only necessary that a device be used that can apply a variable load and has provision for the measurement of drawbar load.

4.1.2 Recorded data for a drawbar pull test should in-

clude the following:

- (a) Drawbar load, lb.
- (b) Engine and wheel (or track sprocket) speed, rpm.
- (c) Vehicle speed, mph.

4.2 SOFT SOIL TESTS -

4.2.1 The determination of drawbar pull for soft soil operation follows similar procedures as for paved surfaces with the exception that there is no interest in the effect of transmission range. The soil is the controlling element in soft soil operation so that the relationship between drawbar pull and slip is of primary interest.

4.2.2 The determination of drawbar pull in soft soil requires the measurement of the following parameters:

- (a) Drawbar load, lb.
- (b) Vehicle speed, mph or fpm.
- (c) Wheel or sprocket speed, rpm.
- (d) Vehicle sinkage, in.
- (e) Vehicle trim, deg.
- (f) Soil strength parameters.

4.2.3 Instrumentation and recording devices will vary depending on the accuracy desired, the magnitude of the test program, and the funds available to support the test program. It is necessary that instrumentation adequately cover the expected range of measurements to be taken without sacrifice of sensitivity or accuracy.

5. PROCEDURE

5.1 PREPARATION OF THE VEHICLE -

5.1.1 In the case of the hard surface tests, the engine should be tuned and adjusted for maximum performance per manufacturer's specifications. Throttle linkage, transmission linkage, and brakes should also be adjusted according to manufacturer's specifications. On automatic transmission equipped vehicles the transmission, clutch, and band adjustments must be checked. In the case of the soft-soil test, the precise adjustment of power train components is not as significant as for the hard surface test, since the soil and suspension are the controlling parameters.

5.1.2 Each vehicle component requiring lubrication must be checked and/or lubricated with the proper quantity and grade of lubricant.

5.1.3 Track tension should be checked and adjusted, if necessary. The tire inflation pressure should be set for optimum off-road performance.

5.1.4 Periodic inspection of the vehicle must be made during testing to insure optimum performance.

5.2 INSTRUMENTATION - The instrumentation for the measurement of most of the test variables appears in separate appendices in the test procedures. The instrumentation requirements for the conduct of a drawbar pull test will be covered in detail only in this Appendix for those instruments not discussed elsewhere. A typical drawbar pull test setup is shown in Fig. A-1.

5.2.1 Drawbar Load - Any of the several types of load measuring devices can be used so long as the appropriate load range is maintained. A standard, commercial load cell using strain gages is economical and adequate. Because of the wide variety of load ranges available, the load cell is a convenient instrument on which to base an instrumentation system.

Hydraulic dynamometers that are rugged and accurate are commercially available. The hydraulic system has the advantage of permitting immediate read-out so that the dynamometer operator can observe the load he is applying to the test vehicle. The hydraulic dynamometer has the disadvantage that a permanent record is not produced. If a permanent test facility of dynamometer vehicle is being considered, a combination load cell hydraulic dynamometer should be given serious consideration. The dynamometer vehicle operator should control the load by observing the hydraulic read-out and the test engineer should maintain control of the test by means of the permanently recorded strain gage measurement.

5.2.2 Vehicle Speed - It is quite possible to measure vehicle speed by recording the time required to traverse a measured distance. However, the use of a fifth wheel to measure speed greatly reduces the complexity of the test procedure, since a continuous reading of speed is obtained. The alternate technique of measuring time and distance requires a close coordination between the measurement of speed and drawbar pull that is quite clumsy.

5.2.3 Engine and Wheel (or Track Sprocket) Speed - In order to compute wheel or track slippage, it is necessary that actual and theoretical vehicle speed be known. Theoretical vehicle speed is obtained by measuring the motion of the driving elements. The engine speed can be measured if the transmission has a lock-up so that there is no slippage between the engine and final drive. Normally, it is more accurate and simpler to measure the speed of the drive sprockets on a tracked vehicle or driving wheels on a wheeled vehicle. Any convenient measuring system can be used, but experience has shown that a tach-generator arrangement produces the most reliable data. No standard attachment is available so that a bracket must be fabricated for each vehicle to be tested. The speed of both drive sprockets on a tracked vehicle must be measured. The speed of all driving

wheels on a wheeled vehicle must be measured unless the vehicle is equipped with no-slip differentials. In this latter case, only the speed of sets of driving wheels need to be measured.

5.2.4 Vehicle Sinkage - It is not necessary to measure vehicle sinkage except for documentary purposes or for verification of the analytical prediction of vehicle performance. The measurement of vehicle sinkage is described in Appendix D.

5.2.5 Vehicle Trim - The measurement of vehicle trim is of value in that an extreme trim attitude will reduce the performance of a vehicle. If a vehicle does not perform as well as anticipated, the measurement of the trim behavior may provide a clue as to the source of poor performance. The measurement of vehicle trim is described in Appendix D.

5.2.6 Soil Strength Parameters - The measurement of drawbar pull in soft soil without an identification of soil properties by some numerical means is virtually useless and may be misleading. The soil properties should be measured by a method that will permit the correlation between soil properties and vehicle performance. Two useful systems are presented in Appendices K and L.

5.3 HARD SURFACE TESTS -

5.3.1 The hard surface drawbar test is conducted on a level, straight, paved surface. The test vehicle, properly prepared and instrumented, is driven prior to testing until all components reach normal operating temperature. The test vehicle is coupled to the dynamometer vehicle and operated throughout the range of speed and transmission ratios established prior to the test. An adequate number of readings should be obtained so that smooth curves of drawbar horsepower versus speed can be plotted for each gear ratio. Wheeled vehicles should be operated with the maximum number of axles driving. Vehicles equipped with automatic transmissions should not be operated at engine speeds near or at transmission shift points, unless a manual selector enables the operator to lock the transmission in gear.

5.3.2 After establishing a steady state condition during a test run, data should be recorded for at least three vehicle lengths.

5.4 SOFT SOIL TESTS -

5.4.1 The soft soil test site selection depends mainly on the type of soil conditions required or desired. At the chosen



Fig. A-1 - Typical drawbar pull test setup



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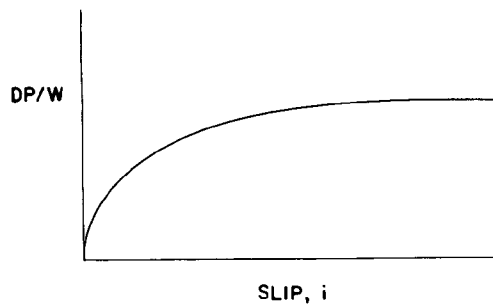


Fig. A-2 - Drawbar pull/weight versus slip

test site, select a smooth flat area with at least a 500 ft straight-away, wide enough to accommodate the test vehicle. The soil should be uniform throughout the test lane. The test lane should be prepared by thoroughly working or mixing the soil to a depth of 20-24 in. until a high degree of homogeneity is obtained. Processing of the soil requires specialized equipment because of the depth of uniform soil required. A gyrotiller with tines rotating about a vertical axis has been the most useful apparatus for the processing of soil in the field.

It is recognized that it may not be economically feasible to construct equipment adequate for processing soil. The alternative to soil processing is a complete measurement of soil strength prior to each drawbar test. Processing of the soil is required after each pass of the test vehicle in order to restore the soil to its original condition to obtain reproducible data. Water, when required, should be applied as evenly as possible.

When conducting drawbar pull tests in snow, processing of the snow is not feasible and a sufficiently large area is required to permit several tests to be conducted. In practice, this requires a 10,000 sq ft, uniform, snow field.

5.4.2 Uniform soil strength, the result of good processing techniques, is essential to the production of reproducible test data. If uniform soil conditions cannot be produced because of a lack of soil processing equipment or for other reasons, it is necessary that extensive soil strength measurements be obtained. An average of the soil property readings along with the variations of the soil properties can provide a guide to the number of tests that must be conducted in order to produce a representative drawbar pull measurement.

5.4.3 During the drawbar pull test, vehicle operating techniques are similar to that used on paved surfaces. However, for determining maximum tractive effort in most soils, the

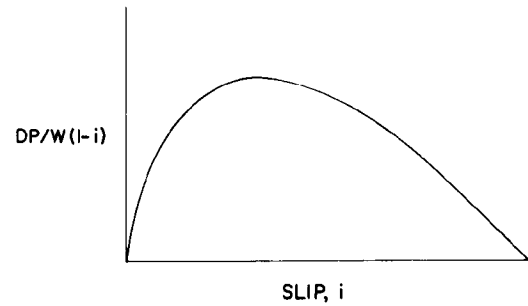


Fig. A-3 - Efficiency versus slip

drawbar load must be sufficient to stop the test vehicle and produce the 100% slip condition. From a practical viewpoint, the maximum drawbar pull at 100% slip is of little interest. For most applications, the test engineer is interested in the drawbar pull at slip rates no greater than 80%. In conducting the test, it is normal procedure to begin the run with no load at the drawbar. The test vehicle is allowed to reach a constant, predetermined rpm. The gear range is only important in that the test vehicle must be capable of developing full track slip (100%) in the soil while maintaining a constant engine rpm. Once a constant rpm is reached, load is applied to the test vehicle incrementally. As each increment of load is applied it is kept constant for a period of approximately 10 sec. The load is increased until the 100% slip point is reached.

6. DATA ANALYSIS

Drawbar pull is one of the essential measurements used in evaluating the mobility of a vehicle and is fundamental to vehicle mobility comparisons. The data are generally presented as maximum drawbar pull developed or as a curve of drawbar pull/weight versus slip (Fig. A-2). Possibly a more revealing curve would be efficiency versus slip, where efficiency is defined as the drawbar work output and equals drawbar pull/weight $\times 1 - \text{slip}$.^{*} This plot is shown in Fig. A-3. This curve has the advantage of indicating the optimum performance point for the test vehicle in a particular soil.

^{*}Dickson, "Some Fundamental Soil Vehicle Mechanics and a Method of Evaluation of the Soil Vehicle System." Canadian Armament Research and Development Establishment, Valcartier, Quebec, 1961.

APPENDIX B

TORQUE

1. INTRODUCTION

In order to conduct a thorough evaluation of vehicle performance, a measure of output torque is essential. The torque applied to a wheel or drive sprocket is of no immediate interest in that the reading itself only provides a knowledge of the efficiency of transmission and other driving elements between the engine and the final drive. However, when output torque measurements are combined with drawbar measurements, it is possible to obtain values for the losses in the suspension and the motion resistance caused by soft soil. It must be recognized that the measurement of torque is a difficult and relatively expensive task and should not be considered as a part of a routine vehicle evaluation. However, when mobility evaluation is a part of a vehicle development program, the measurement of output torque is essential to a full understanding of the source of a deficiency in performance.

The use of the output torque measurement requires that measurements be made on both hard surfaces and in soft soil. Further, the measurement in soft soil should be made simultaneously with drawbar pull for maximum utilization of data. The measurement of torque independent of drawbar pull provides an index of losses due to ground resistance, wheel or track slippage, and suspension clogging. The hard surface test develops the relationships between torque and track or vehicle speed, as long as the measure of the relationship between torque and track speed is made at constant vehicle speed, the gear range is of no consequence. The curve that is obtained from this test serves as a base line indicating internal resistances which are the suspension losses caused by such things as friction in the various elements and acceleration of the track. It is obvious that almost an identical result could be obtained by disconnecting the final drive or axles towing the vehicle at an equivalent group of speed intervals. By measuring the towing force to produce a constant speed, the suspension losses can be identified. The only difference between the two sets of readings would be caused by the torque reaction when the vehicle is driven instead of towed.

When combined with the soft soil test results, the hard surface torque measurement permits the identification of motion resistance developed by the soil. The difference between the traction that the output torque should produce and the drawbar pull can be attributed to three losses:

- (a) Internal resistance.
- (b) Soil motion resistance.
- (c) Suspension losses caused by accumulation of soil or other surface materials.

The internal resistance is obtained from the hard surface test. The suspension losses caused by accumulation of extraneous material is obtained from the 100% slip point. If track or wheel speed is constant at 100% slip, the difference between the gross traction, as measured by the output torque, and the drawbar pull is equal to the sum of the internal re-

sistances and the losses caused by accumulated material. The motion resistance is equal to the difference between gross tractive effort and the sum of the suspension losses.

2. DEFINITION

Output torque is the torque applied to the final driving elements of a vehicle such as a wheel or sprocket.

3. PURPOSE

The output torque is used to determine resistance to motion on both hard (paved) surface and soft soil. The resistance to motion is subdivided into ground losses and suspension losses permitting identification of sources of performance deficiencies.

4. APPARATUS

When possible, torque is measured by means of a commercial torque meter mounted between the final driving element and the input to the final drive. However, in most cases, it is necessary to apply strain gages to the shafts leading to the final drive or to the axles. Slip rings are required to feed the strain gage signals to a recorder so that the installation is quite expensive and time consuming. Because each installation is unique, no standard instrumentation procedure is offered for the measurement of torque. The measurement of track or wheel speed is identical to that used in the drawbar pull test (Appendix A). Torque measurement is of little use unless measured concurrently with speed measurement. The reader is thus referred to Appendix C.

5. PROCEDURE

5.1 HARD SURFACE TESTS - The output torque should be measured on a level paved surface over the vehicle speed range. Steady state speed should be maintained for a minimum of ten seconds or until the torque readings become constant. The speed increments should be chosen to result in a reliable torque-speed curve.

5.2 SOFT-SOIL TESTS -

5.2.1 The output torque is measured in soft soil concurrently with drawbar pull. The procedure for the drawbar pull test, therefore, controls the procedure used to measure torque. (See Appendix A.)

5.2.2 If a vehicle has been instrumented to measure output torque, a valuable addition to the Observational Type Test can be obtained by measuring torque during the test. It must be observed, however, that the results of the measurements are more useful for design than evaluation purposes. A history of power requirements related to obstacle configuration would permit establishment of design criteria. One objective of this recommended practice is to develop such data.

6. DATA ANALYSIS AND PRESENTATION

6.1 Output torque data from the hard surface tests should be presented as torque versus speed curves.

6.2 The presentation of the soft-soil results can follow any pattern desired by the test engineer. It is suggested that the data follow both a graphical and tabular format:

(a) The output torque should be presented graphically plotted against wheel or track speed.

(b) The soil motion resistance should be presented graphically against wheel or track slip.

(c) The suspension internal resistance and resistance due to accumulated material should be tabulated, since these values tend to be relatively independent of track or wheel speed at the speeds at which drawbar tests are conducted.

6.3 For observational type tests, the output torque signal should be identified with the terrain conditions. The torque data may be presented as torque required to overcome an obstacle versus obstacle type. A useful presentation technique is the use of a double plot: one curve identifying the terrain profile and the second curve identifying the torque level associated with each point on the profile.

APPENDIX C VEHICLE SPEED

1. INTRODUCTION

There are many situations in which vehicle speeds are taken as the primary measure of vehicle performance. For example, when identifying the off-road performance of a vehicle operating over a cross-country course, a logical measure of performance is "speed made good." That is, a straight line distance between two points divided by the time required to complete the course. In other circumstances, the actual vehicle speed must be measured in order to be included as a variable. An example is the development of drawbar pull versus speed data. The method used to determine vehicle speed depends upon the final use of the measurement, the accuracy required, and the particular test situation which may prescribe the measuring method to be used.

2. DEFINITION

Vehicle speed is the rate of travel, that is, the total distance travelled divided by the time to traverse the distance.

Vehicle speed made good is defined as the straight line distance between two points divided by the time required to move between the two points.

3. PURPOSE

Vehicle speed is measured as a test variable or as the primary performance evaluation criterion. In the conduct of cross-country or trail operation tests, it is desirable to consider speed made good rather than vehicle speed because the latter value may have little significance. For example, one vehicle may be capable of moving at a higher rate than a second vehicle but if the second vehicle has other characteristics that permit it to take a shorter route, the second vehicle may arrive at the destination before the faster moving but less useful vehicle.

Speed is, of course, also measured as the primary variable in various gear ranges.

In several types of tests, speed is a "secondary" variable. It is measured to permit the establishment of the variation with speeds of the primary variable of interest. For exam-

ple, the measurement of resistance to propulsion is made throughout the speed range of a vehicle to determine the relationship between losses and speed. In this example, speed is of no interest in itself; speed is measured in order to record the variation of the parameter of interest.

4. APPARATUS

Because of the wide variation in methods of measuring vehicle speed, instrumentation details will not be specified. Time and distance must be measured by some means. Time may be recorded by means of an electronic counter, a stop watch, an event marker on a paper recorder, or any similar device. The length of the time to be counted will establish the sophistication of the measuring apparatus.

Distance can be measured by means of a standard automotive fifth wheel; by measuring the distance prior to the test and timing the run to traverse the distance; by measuring the distance on a map for large distances; or by any conventional method which produces a measurement sufficiently accurate for test requirements.

The measurement of both time and distance are considered sufficiently well known to make a detailed description superfluous.

5. PROCEDURE

5.1 MEASUREMENT OF AVERAGE SPEED - Because of relatively long distances involved in cross-country operations and because the primary factor of interest is usually comparative performance, the measurement of cross-country speed can be relatively simple. If speed is to be based on actual distances traveled, the distance can be measured by means of the odometer on one of the test vehicles and this distance taken for all vehicles in the test. Time can be measured by means of stop watch readings of starting and stopping time.

If "speed made good" is to be taken as the performance measure, it is necessary to have adequate map coverage to provide a distance measurement within $\pm 2\%$. If maps are not available, it is necessary to resort to standard surveying

methods to establish the straight line distance. The cost and effort of this measurement is not considered justifiable unless the test course is to be used on a repetitive basis.

5.2 MEASUREMENT OF ACTUAL SPEED - When a test requires that actual speed be measured, a higher order of accuracy is required than for the measurement of average speed. When concerned with actual speed, the test engineer usually must have an immediate speed read-out since speed must be maintained at a specific level.

The most common method of measuring actual speed is by means of a fifth wheel attached to the rear of the test vehicle. The fifth wheel drives a standard Weston Meter (tach-generator) which reads directly in miles per hour.

If a fifth wheel is not available, the test engineer may be forced to operate on the basis of the test vehicle speedometer. Under this circumstance, the speed reading should be checked by an alternate method. The speedometer can be used to provide immediate read-out to maintain a constant speed level and the actual speed level established by the time required to complete a measured distance. In order to reduce error caused by the averaging process, the measured distance should be kept short -- of the order of 100 ft. Time can be measured by means of a stop watch.

If a high degree of accuracy is required in the measurement of vehicle speed, it is possible to obtain commercial units normally applied to racing events such as drag racing or to police work. The former units likely exceed the requirements of vehicle testing. Photocells and counterchron-

ographs are used to obtain time with an accuracy of ± 0.01 sec. Speed can be measured and read directly by setting the photocells at known distances and converting the counter-chronograph reading to mph rather than time units.

The police type of radar has adequate accuracy as attested by the acceptance of its results as legal evidence. The system can provide a reading of speed taken over a very short distance, which can be a definite advantage when attempting to establish a given speed level. The advantage is lost, however, unless the read-out equipment is mounted on the test vehicle. It should be possible to mount the radar equipment on the test vehicle and shoot at a fixed target on the course and thus provide both accurate speed readings and immediate read-out for the test engineer or vehicle operator.

6. DATA ANALYSIS AND PRESENTATION

The analysis and presentation of vehicle speeds depend upon the use of the data. Analysis of the data is more or less restricted to a determination that the speed values measured are correct.

When speed is the primary parameter studied in a test, the results normally are presented in tabular form, that is, the maximum speed in each transmission range. When speed is a control variable, the relationship between the test variable and speed can best be shown graphically. Because of the large number of parameters that are tested against speed, no examples are offered.

APPENDIX D VEHICLE SINKAGE AND TRIM

1. INTRODUCTION

The measurement of vehicle sinkage and trim during soft-soil drawbar pull tests assist in the description and analysis of performance. Motion resistance is proportional to both sinkage and trim and gross traction can vary significantly with trim. Since motion resistance and gross traction determine drawbar pull, it is necessary that sinkage and trim be measured in order to understand and interpret the results of a drawbar pull test.

2. DEFINITIONS

2.1 Vehicle sinkage is the result of the vertical deformation of soil due to the loads imposed by the vehicle weight and the traction elements. Sinkage can be taken as either static or dynamic sinkage. Static sinkage is caused by the vehicle weight when no forward motion of the vehicle occurs. Dynamic sinkage is produced by vehicle weight and by the disturbance of the soil resulting from the shearing action of the tracks or wheels, that is, the slip-sinkage phenomenon. Many soils produce approximately equal static and dynamic sinkages but granular materials, such as sand or snow, may produce dynamic sinkages several times as great

as the static sinkage. Dynamic sinkage is the appropriate measurement for the analysis of drawbar pull data, since this is the depth to which the vehicle actually sinks during operation.

2.2 Vehicle trim is the attitude that a vehicle assumes relative to the ground surface as it moves over the surface.

3. PURPOSE

3.1 Measurement of vehicle sinkage during off-road tests permits the computation of motion resistance and ground pressure if the soil strength characteristics are also measured. Motion resistance is proportional to the work involved in causing the soil to deform to a depth equivalent to the vehicle dynamic sinkage. The ground pressure is proportional to static sinkage unless vehicle trim is in excess of 5 deg. For small trim angles, average ground pressure can be computed using the pressure-sinkage relationship of the soil and the static sinkage of the vehicle.

3.2 Vehicle trim is measured in order to identify non-uniform ground pressure distribution which results from weight transfer. In addition, increase in motion resistance caused by sinkage associated with weight transfer can be identified. A severe trimmed attitude is a source of