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14. ABSTRACT
This TOP describes test methods to be utilized for evaluating wheeled and tracked vehicle gradeablility and side slope performance. Included are procedures for calculating the vehicle critical angle, evaluating engine, transmission, brake system, and fuel system performance, and defining vehicle stability and control during grade and side slope testing.

15. SUBJECT TERMS

Gradeability	Critical angle	Tilt table
Braking system	Drawbar pull	Side slope
Towed dynamometer	Percent grade	Sine wave pattern
Fuel system		

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US ARMY DEVELOPMENTAL TEST COMMAND
TEST OPERATIONS PROCEDURE

*Test Operations Procedure 02-2-610 03 December 2009
DTIC AD No.: ADA526365

GRADEABILITY AND SIDE SLOPE PERFORMANCE

*This TOP supersedes TOP 02-2-610, dated 18 July 1980.

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1. SCOPE.

This Test Operations Procedure (TOP) describes the test methods utilized for evaluating wheeled and tracked vehicle performance on longitudinal and side slopes of varying degrees of grade. Included are procedures for evaluating engine, transmission, brake system, and fuel system performance and vehicle stability and control during grade and side slope testing.

The vehicle capabilities for operating on slopes are of particular interest in military vehicles; which must be capable of operating in any tactical situation without relying on established roadways. The evaluation of the gradeability and side slope performance of a vehicle on calibrated grades provides a means for determining the adequacy of the equipment, and provides for an assessment of its tractive effort.

2. FACILITIES AND INSTRUMENTATION.

2.1 Facilities.

Item	Requirement
Longitudinal grades and side slopes	Grades and slopes as described in TOP 01-1-011[1]**. Representative photos appear as Figures 1 and 2
Safety vehicle with safety cable	Vehicle of sufficient weight with a cable of sufficient size and strength to safely restrain the test vehicle in the event tipping, mechanical failure, or if tread slip occurs
Tilt Table	A single continuous platform capable of tilting a test vehicle parallel to its longitudinal axis. The platform must remain essentially planar throughout testing
Level, paved test course	A straight, level, paved road with a width of not less than 3.7m, a longitudinal gradient $\leq$ 1%, and a side slope gradient $\leq$ 2%. The length of the roadway should be sufficient to allow the test vehicle with the required towed dynamometer loaded to accelerate to, and maintain the corresponding stabilized speed

** Superscript numbers correspond to those in Appendix A, References.

Figure 1. Vehicle on 60% Longitudinal Grade.

Figure 2. Vehicle on Side Slopes.

2.2 Instrumentation.

Devices for Measuring	Permissible Measurement Uncertainty (see NOTE 1)
Road speed.	1%
Engine speed.	1%
Pressure (vehicle fuel, oil, tire, etc.).	1%
Tilt table angle.	0.2 deg
Applied drawbar load	1%
Meteorological data:	
Atmospheric pressure.	1%
Ambient temperature.	1 °C
Humidity.	3%
Wind speed.	5%
Wind direction.	50 mrad

Note 1: The permissible measurement uncertainty is the two-standard deviation value for normally distributed instrumentation calibration data. Thus 95% of all instrumentation calibration data readings will fall within two standard deviations from the known calibration value.

2.3 Specialized Equipment.

Specialized equipment/instrumentation that may be required for testing are as follows:

a. Towed dynamometer. This is typically an eddy-current power absorber capable of applying a resistive load proportional to the desired longitudinal grade. It is equipped with an on-board load-cell and road speed magnetic pick-up sensor to measure drawbar pull and road speed respectively, for control feedback and data acquisition.

b. Still cameras and/or video cameras to record vehicle-to-surface contact, stability and control problems, and track/wheel slip.

c. When driveline torque and/or steering evaluations are requested as part of this testing, the additional instrumentation required is described in TOP 02-2-806[2] and TOP 02-2-002[3] respectively.

3. REQUIRED TEST CONDITIONS.

3.1 Preparation for Test.

a. Review all instructional material issued with the test vehicle by the manufacturer, contractor, or government, as well as reports of previous similar tests on the same types of vehicles.

b. Select the applicable test facilities to be used based on the requirements documents and purpose of the test. Review the applicable test procedures listed in the detailed test plan.

c. Prepare data collection sheets to record all pre-test information, conditions of test, test results, observations, and measurements that would be valuable in analysis and assessment.

d. Ensure that all test personnel are familiar with the required technical and operational characteristics of the item and the required test procedures.

3.2 Determination of Critical Angle.

3.2.1 General Description.

When negotiating slopes of critical grade, vehicles tend to tip over about some pivot point. In theory, the critical point is reached when the center of gravity (CG) of the vehicle is located vertically above its center of rotation (Figure 3). In practice, the actual critical angle is always less than the theoretical value during both static and dynamic operations. Statically, the sagging of suspension members causes the CG to shift toward the center of rotation. Dynamically, this condition is amplified by the torque imposed by the driveline, especially when accelerating.

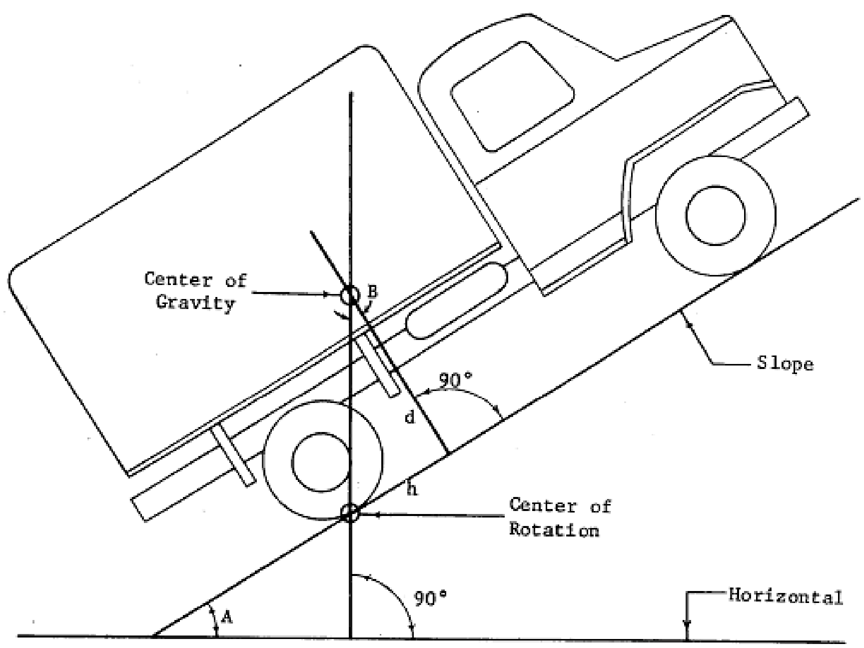

Figure 3. Critical Angle for Vehicle on Longitudinal Slope.

3.2.2 Method of Determination.

a. Calculation Method. The theoretical critical angles (tipping angles) are calculated for each direction of operation of the test vehicle before testing, to establish an approximation of the maximum slopes on which the vehicle can safely operate. For these calculations, the vehicle is assumed to be at its designated test weight and the CG was determined in accordance with TOP 02-2-800[4]. With the vehicle on level ground, the height (d) of the CG above ground and horizontal distance (h) between the CG location and the center of rotation (in this case, the rear wheels) are measured. These measurements are used in the following equations to determine the theoretical values for the critical angle and the critical grade (slope) expressed as a percentage.

$$\text{Critical Angle B} = \tan^{-1} h/d$$

$$\text{Critical Grade (\%)} = 100\ h/d$$

At the critical angle, the CG is directly above the center of rotation; therefore, angle A equals angle B.

For the procedure presented above the critical angle was obtained for a vehicle ascending a longitudinal grade. Critical angles for a vehicle descending a grade and for side slope operations are obtained in a similar manner.

b. Tilt Table Method. Utilizing a tilt table to rotate the test vehicle about its center of rotation, the vehicle critical angles and grades are determined in accordance with the procedures presented in Society of Automotive Engineers (SAE) recommended practice J2180[5].

3.3 Test Controls.

a. Prior to testing ensure that:

(1) The vehicle has been prepared and equipped in accordance with standard use and/or within the specifications presented in the test plan, with particular attention being given to the engine, transmission, brakes, running gear, and fuel and oil levels.

(2) The vehicle is payloaded in accordance with the test plan and the payload is secured in a safe and proper manner.

(3) The vehicle has received the proper break-in operation.

(4) Vehicle tires or track pads are in good serviceable condition, and the tire pressure or track tension is adjusted to the proper settings.

(5) Prior to grade operations the tire and wheel at the bead interface should be marked to allow a visual check of bead slip and possible loss of traction during testing.

b. All safety procedures must be observed throughout test operations. In particular, safety cables, used in conjunction with a properly sized anchor vehicle, are attached to all test vehicles when negotiating longitudinal slopes greater than 40 percent and side slopes whose grade approaches the tipping angle measured during tilt table testing. Operation without a safety cable may be permitted only after previous testing of a “like” vehicle (similar total weight, CG, and dimensions) has demonstrated that the vehicle can safely negotiate the specified slope.

3.4 Restrictions.

Tests are not conducted at night or during inclement weather. Test course safety and operational procedures will be carefully followed.

4. TEST PROCEDURES.

4.1 Longitudinal Grade Performance.

Usually military specifications require that tactical and combat vehicles be able to negotiate a 60-percent grade in both forward and reverse gears and have adequate braking capability to hold the vehicle stationary on this grade. Generally, all military vehicles are required to demonstrate gradeability on designated grades at specified speeds without stalling, upsetting, losing traction, and overheating the engine. These procedures will allow the determination of those capabilities.

4.1.1 Braking System Grade Holding Ability.

The vehicle’s service and parking brake systems, each independent of the other, should be capable of holding the vehicle stationary in both ascending and descending attitudes on the maximum longitudinal slope over which the vehicle is required to operate.

a. The vehicle is positioned on dry, paved, longitudinal slopes in both ascending and descending directions.

b. In accordance with the recommended guidance, the service and parking brake systems are engaged separately to assure their individual capability to hold the vehicle stationary. The test sequence should as a minimum be as follows:

(1) Position the test vehicle on the designated grade.

(2) Apply the service/parking brake(s).

(3) Disengage the transmission.

(4) If testing the parking brake, release the service brake.

(5) Turn off the engine.

(6) Wait a minimum of five minutes.

(7) Observe wheel or track movement.

c. When testing a trailer or semi-trailer, a safe disconnect (mechanical, electrical, pneumatic, and hydraulics connections) from the prime mover must be maintained.

4.1.2 Vehicle Engine and Transmission Performance.

a. Prior to testing, vehicle fluids are adjusted to specified levels.

b. With the vehicle positioned on the specified grade, its engine will be idled for two minutes, shut down for two minutes, and then attempted to be restarted. If the engine is restarted, engage the transmission and increase the throttle as the brakes are released, to determine the vehicle's ability to continue grade ascent. When applicable, auxiliary engines are also checked for idling and restart capability.

c. This procedure is performed with the vehicle positioned in both the ascending and descending attitudes.

d. If the test vehicle is equipped with a Central Tire Inflation System (CTIS), the test procedure will be performed with the tire pressures adjusted to the recommended settings for grade operations.

e. During grade operations, observations of any fluid overflow (oil, fuel, water, etc.), change in fuel and oil pressures, and tire-to-wheel bead slip are noted.

f. When requested, for vehicles with torque-converter transmissions, the engine speed at vehicle stall is observed with the vehicle ascending slopes of maximum grade. This can be an indication of whether the engine is delivering appropriate torque and horsepower.

4.1.3 Longitudinal Slope Speed.

a. On the steeper grades, the maximum sustained speed of the test vehicle is determined by accelerating the vehicle from a standing start on the grade. A number of trials may be required to determine the optimum speed/gear combination for maximum performance.

b. On slopes of lesser grade that lack sufficient length, the vehicle's maximum sustained speeds are obtained by making running approaches to the designated slope at predetermined speeds. Once on the slope maximum throttle is applied. During subsequent runs, the slopes are approached at a speed equal to the maximum speed attained during the previous run. This process is repeated until the maximum sustained speed is reached.

c. If the desired gradient is not available, vehicle slope performance can be calculated utilizing its drawbar pull performance. By referencing its drawbar pull curves, both the vehicle's gradeability at a given speed and its maximum speed at a given gradient may be determined. The formulas for making these determinations are:

$$\text{Sin } \theta = P \div W$$

$$\text{Percent grade} = \tan \theta \ (100)$$

where

θ = Angle of grade.
P = Drawbar pull value.
W = Vehicle test weight.

d. Alternative methods for measuring the maximum sustained speed required by a vehicle to negotiate slopes of lesser grade (usually 5 percent or less), where a longer grade is needed, are as follow:

(1) Using a towed dynamometer (paragraph 2.3.a), a resistive load is applied equal to the force imposed by the designated grade as the vehicle is operated at full throttle on a level, paved test course. If the test item involves a prime mover with trailer, the additional rolling resistance associated with the driveline and wind resistance of the trailer must be accounted for in the resistive loading. Typically, four data runs, two in each direction, are averaged to obtain the maximum sustained speed in the optimum transmission gear for the specified grade.

(2) In the absence of a dynamometer, the maximum sustained vehicle speeds required to ascend grades less than 5 percent can be determined through the use of appropriate sections of public highways. The highway must be surveyed to assure the designated section corresponds to the desired grade. When operating on public highways care must be taken to adhere to all local, state, and federal laws. Also, additional safety precautions should be considered, when appropriate, to include the use of escort vehicles to provide warning to local traffic.

4.2 Side Slope Performance.

Military vehicles are tested to determine their capability for negotiating side slopes of varying grade, as required in the applicable specifications.

a. Prior to testing, fluids are adjusted to specified levels.

b. On the designated slope, the vehicle is operated in both directions in a sine wave pattern at a minimal speed ($\leq$ 8 km/hr) to evaluate its dynamic stability, adequate steering control, and tracking (reference TOP 02-2-002).

c. With the vehicle positioned on the required slope in each direction, its engine will be idled for two minutes, shut down for two minutes, and then attempted to be restarted. If applicable, the same procedure is followed for the auxiliary engine.

d. During slope operations, any fluid overflow (oil, fuel, water, etc) and change in fuel and oil pressures are observed as well as fuel flowing from a high-side tank to a low-side tank.

e. Any observations of tire bead unseating from the wheel or misguiding of track will be reported.

4.3 Other Performance Factors.

During longitudinal grade and side slope testing, the following observations are made as appropriate, to determine the effect of grades and slopes on other performance factors:

a. The ability of the driver to remain in an adequate position to control the vehicle (i.e., steer, apply brakes, visibility).

b. The security of payloads (reference TOP 02-2-537[6]).

c. The security of basic issue items (BII) (reference TOP 02-2-802[7]).

d. Adequacy of vehicle design to accommodate the angles of approach, departure, and breakover required for grade negotiation.

5. DATA REQUIRED.

5.1 Longitudinal Grade Performance.

5.1.1 Braking System Grade Holding Ability.

a. Percent grade.

b. Vehicle position (ascending/descending).

c. Distance vehicle moved, if at all (note wheel/track role or slide).

d. Test duration.

e. Brake control force, if required.

f. Brake temperatures, if required.

g. Comments on vehicle behavior.

5.1.2 Engine and Transmission Performance.

a. Calculated critical angle/grade, if required.

b. Percent grade and direction of travel.

c. Vehicle test configuration (payload, weight, tire pressures, fuel and oil levels, etc).

d. Observations of engine idle and restart capabilities and ability of vehicle to continue slope climb.

e. Location and approximate amount of any fluid overflow.

f. Observations of adequacy of vehicle steering and stability.

g. Engine speed.

h. Fuel and oil pressures.

i. Observations of tire-to-wheel bead slip.

j. Engine accessories operating mode.

5.1.3 Longitudinal Slope Speed.

a. Percent grade.

b. Vehicle test configuration (payload, weight, tire pressures, fuel and oil levels, etc).

c. Road and engine speeds, and gear range of each test run.

d. Calculated and actual drawbar loading supplied by the towed dynamometer.

e. Fuel and oil pressures when requested.

5.2 Side Slope Performance.

a. Vehicle critical angle/slope determined during tilt table testing.

b. Percent slope and direction of travel.

c. Vehicle test configuration (payload, weight, CG location, fuel and oil levels, etc).

d. Road speed.

e. Engine speed.

f. Fuel and oil pressures.

g. Steering and stability observations.

h. Engine starting ability.

i. Observations of tire bead unseating or track misguide.

j. Location and approximate amount of any fluid overflow.

k. Engine accessories operating mode.

6. PRESENTATION OF DATA.

At a minimum, the following results will be presented in a tabular format and compared to the criteria and, when requested, the results of other test vehicles.

a. Vehicle critical angle/slope for each direction tested.

b. Maximum grade holding ability for each brake system tested and vehicle direction.

c. Maximum road and engine speeds and gear range of the vehicle for each longitudinal grade tested.

d. Engine idle and restart and vehicle climbing capabilities for each grade tested.

e. Engine idle and restart capabilities and steering and stability observations for each side slope tested.

Examples of typical tables utilized for data presentation are presented in Figures 4, 5, and 6.

TABLE 2.10-4. LONGITUDINAL GRADE PERFORMANCE, VEHICLE XXX AT GVW.

Grade - %	Orientation	Climbing Ability	Pressure		Brake Holding Ability		Engine Idle and Restart
			Fuel	Oil	Service	Parking	
40	Ascending	Satis	OK	OK	Satis	Satis	Satis
	Descending	Satis	OK	OK	Satis	Satis	Satis
50	Ascending	Satis	OK	OK	Satis	Satis	Satis
	Descending	Satis	OK	OK	Satis	Satis	Satis
60	Ascending	Satis	OK	OK	Satis	Satis	Satis
	Descending	Satis	OK	OK	[a]Unsatis	[a]Unsatis	Satis

[a]Rear axle brakes locked wheels but weight transfer allowed vehicle to slide down slope.

Figure 4. Longitudinal Grade Performance Data Presentation.

TABLE 2.10-5. MAXIMUM SUSTAINED SPEEDS ON LONGITUDINAL GRADES, VEHICLE XXX AT GVW.

Grade - %	Sustained Road Speed		Engine Speed, rpm	Trans. Gear	Transf. Range
	km/hr	mph			
[a]2	88.5	55.0	2575	5L	High
[a]3	68.7	42.7	2650	4L	High
[b]5	49.4	30.7	2700	3L	High
10	31.4	19.5	2390	5L	Low
15	24.1	15.0	2380	4L	Low
20	17.7	11.0	2490	3L	Low
30	12.9	8.0	2390	2L	Low
40	7.9	4.9	2700	1L	Low
50	7.9	4.9	2640	1L	Low
60	4.0	2.5	1930	1C	Low

[a]Obtained through use of towed dynamometer.
[b]Calculated from drawbar pull data.

Figure 5. Longitudinal Grade Sustained Speed Data Presentation.

TABLE 2.10-6. SIDE SLOPE PERFORMANCE, VEHICLE XXX AT GVW.

Grade - %	Upslope Orientation	Engine		Pressure		Sine Wave Stability
		Idle	Restart	Fuel	Oil	
20	Left Side	Satis	Satis	OK	OK	Satis
	Right Side	Satis	Satis	OK	OK	Satis
30	Left Side	Satis	Satis	OK	OK	Satis
	Right Side	Satis	Satis	OK	OK	Satis
40	Left Side	Satis	Satis	OK	OK	[a]Unsatis
	Right Side	Satis	Satis	OK	OK	[a]Unsatis

[a]During the performance of the sine wave steer maneuver, the vehicle upslope wheels on the rear axle exhibited limited traction.

Figure 6. Side Slope Performance Data Presentation.

APPENDIX A. REFERENCES.

1. Test Operations Procedure (TOP) 01-1-011, Vehicle Test Facilities at Aberdeen Proving Ground, 6 July 1981.

2. TOP 02-2-806, Power Train Torque Measurements, 30 December 1994.

3. TOP 02-2-002, Dynamic Stability, Handling and Steering, 19 May 2009

4. TOP 02-2-800, Center of Gravity, 26 September 2006.

5. Society of Automotive Engineers (SAE) Procedure, J2180, A Tilt Table Procedure for Measuring the Static Rollover Threshold for Heavy Trucks, December 1998.

6. TOP 02-2-537, Cargo Loading Adaptability, 15 April 1971.

7. TOP 02-2-802, Stowage, 9 January 1979.

Forward comments, recommended changes, or any pertinent data which may be of use in improving this publication to the following address: Test Business Management Division (TEDT-TMB), US Army Developmental Test Command, 314 Longs Corner Road Aberdeen Proving Ground, MD 21005-5055. Technical information may be obtained from the preparing activity: Automotive Instrumentation Division (TEDT-AT-AD-I), US Army Aberdeen Test Center, 400 Colleran Road, Aberdeen Proving Ground, MD 21005. Additional copies can be requested through the following website: http://itops.dtc.army.mil/RequestForDocuments.aspx, or through the Defense Technical Information Center, 8725 John J. Kingman Rd., STE 0944, Fort Belvoir, VA 22060-6218. This document is identified by the accession number (AD No.) printed on the first page.