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14. ABSTRACT
Describes procedure for evaluation of vehicle power available for acceleration, towing, or hill climbing. Defines drawbar pull. Includes procedures for hard surface, soil, and water tests. Discusses vehicle preparation, instrumentation method of computing results, data reduction, and presentation. Establishes curves for comparing performance with similar vehicles and for predicting gradeability. Applicable to wheeled, tracked, and amphibious vehicles.

15. SUBJECT TERMS
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TEST OPERATIONS PROCEDURE

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DRAWBAR PULL

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1. SCOPE. This Test Operations Procedure (TOP) describes the procedures for determining the drawbar pull characteristics of wheeled and tracked vehicles on hard-surfaced roads, in soft soils, and of amphibious vehicles in water.

*This TOP supersedes TOP 2-2-604, dated 18 July 1980.

Drawbar pull provides a measure of the reserve power available to a vehicle (in excess of that required for vehicle propulsion on a level road) for acceleration, towing, or hill climbing. Vehicles are tested for drawbar pull to establish performance curves that can be used for evaluations and comparisons with similar vehicles. These data also serve to predict gradeability when no facilities are available for determining slope performance at a desired gradient (TOP 2-2-610[1**]).

2. FACILITIES AND INSTRUMENTATION.

2.1 Facilities.

Item	Requirement
Mobile Field Dynamometer	As described in TOP 2-1-005[2]
Test Courses	
Level Paved Course	Less than 1% grade
Soft Soil	Sand or other fine-grained soil course Mud or wet clay soil course
Water Test Facility	As required

2.2 Instrumentation.

Item	Maximum Error of Measurement (See NOTE)
Force-measuring device	±0.5% of full-scale range
Vehicle speed-measuring device (with speed indicator)	±0.2 km/hr or ±0.2 mph
Tachometers (engine and wheel or sprocket speeds)	±0.5% of full-scale range
Temperature-measuring devices	±2˚C (3.6ºF)
Pressure-measuring devices (oil, fuel, etc.)	±l% of full-scale range
Fuel consumption measuring device	±2% of full-scale range
Cone pentrometer	±5% of reading
Percent soil moisture content	±1%
Soil depth (to hardpan)	±2 cm
Data bus reader (if vehicle so equipped)	As required
Relative humidity	±3% (0 to 90%) and ±4% (90 to 100%)
Barometric pressure	±1.0-mm Hg (±1.4 hPa/mb)
Wind speed	±2 kts, 3 km/hr, 1 m/s, or ± 5% (whichever is higher)
Wind direction	±7 degrees

NOTE: Values may be assumed to represent ±2 standard deviations. Thus, the stated tolerances should not be exceeded in more than one measurement out of 20.

[**] Superscript numbers/letters correspond to those in Appendix A, References.

3. REQUIRED TEST CONDITIONS.

3.1 Vehicle and Test Preparations.

Maintenance and service operations are performed to insure that the vehicle is in condition for optimum performance, with particular attention being given to the engine, transmission, and running gear. A check is made to ensure that the proper grade and quantity of lubricant have been used. Unless otherwise specified, the vehicle is loaded with its normal payload or combat weight. Vehicle characteristic data are collected in accordance with (IAW) TOP 2-2-500[3].

The vehicle tires should have a minimum of 50 percent of tread depth remaining. Tread depths should be measured as this impacts rolling diameter of the tires and the drawbar pull. Vehicle tracks should be in good condition and properly adjusted. For soft soil drawbar, either new tires or new track in proper adjustment should be used.

The tire pressure should be set as specified in the Technical Manual (TM) or Detailed Test Plan (DTP). Tire pressures should be recorded as this can affect the rolling diameter of the tires and results.

Perform oil analysis on critical component fluids as required.

3.2 Instrumentation.

The vehicle is instrumented to determine the drawbar pull (generally installed on dynamometer), engine speed, road speed, and track or wheel speed of the vehicle and to monitor (as applicable) the pressures and temperatures of the engine and transmission oil and fuel and cooling systems. As high loads are applied to the vehicle during drawbar pull, at a minimum, the critical fluid temperatures must be measured to avoid potential overheating during the test. The instrumentation commonly used consists of a mobile field dynamometer, an engine speed measuring device, a calibrated speed measuring device with a speed indicator for the driver, sprocket or wheel tachometers, and the appropriate pressure gages and thermocouples. The temperatures are generally sampled at once per second, while the speeds and pressures are generally sampled at ten times per second. When full load fuel consumption is measured as part of this test, additional instrumentation is installed in the vehicle as described in TOP 2-2-603[4].

If the vehicle is equipped with a data bus, the data stream should be monitored and recorded. The data bus can provide key information for drawbar tests, including gear ranges, torque converter lockup, throttle position, component temperatures, fuel consumption rates, etc. The validity of the data bus information must be verified or the source of data documented.

For soft soil operations, a cone penetrometer is required to obtain the cone index (reference FM 5-430-00-1, Chapter 7[5] for measurement procedures). Also, a non-contact fifth wheel, radar gun, or line payout device is required to obtain vehicle speed.

3.3 Test Controls.

a. All safety Standard Operating Procedures (SOPs) are observed throughout test operations.

b. Correct levels of lubricant, hydraulic fluid, coolant, etc., are maintained throughout the tests.

c. Vehicles are operated until their normal operating temperatures are reached before initiating each test.

d. Critical fluid temperatures must be monitored during the test. The high loads placed on the drive train could potentially result in overheating of fluids. The drawbar load should be reduced and fluids allowed to cool if this occurs during test.

e. A minimum of 30 seconds of data should be collected at each load condition. Drawbar measurements are conducted in both directions on the test course if there is any grade, and the readings are averaged.

f. Tests are conducted at full throttle, with vehicle speeds and gear ranges controlled by varying the applied load with the dynamometer vehicle. The test should be conducted at as wide a speed range as possible within the limitations of the load application equipment. During soft soil testing, the applied load shall be sufficient to produce 100 percent slip or very near 100 percent slip.

g. The drawbar connection between the test vehicle and dynamometer needs to be inspected, under load, for a level connection. Any difference between the height of the drawbar at the test item and dynamometer can result in force being measured at an angle and could introduce error.

h. All soft soil courses shall be prepared IAW applicable TOPs and International Test Operating Procedures (ITOPs) (ref TOP 2-2-619[6] for soft soil). Each test run shall be conducted on an untracked portion of the test course.

i. Do not wait until the test is over to check over the data. It is especially desirable to plot drawbar pull and engine speed data versus road speed immediately as obtained to assure its quality. Certain points may have to be rerun and averaged.

j. Brief the operator about stopping without signals from the dynamometer crew. If the operator stops without the dynamometer crew being ready, considerable damage may be done to the equipment.

4. TEST PROCEDURES.

4.1 Drawbar Pull (Common).

Method. This test is conducted with the test vehicle connected at the tow points to another low-friction load, usually dynamometer or another vehicle. A load cell or other force measuring instrumentation is installed at the test vehicle tow point to measure the amount of force the test vehicle is exerting on the load vehicle. The available power at the test vehicle tow point is measured in as many gear combinations as possible over the speed range of the vehicle at full throttle and full load, at discrete points in the normal operating speed range of the engine.

a. Drawbar pull (DBP) for vehicles with direct mechanical transmissions or automatic transmission when torque converter lockup is achieved may be computed for those gear ranges that cannot be measured safely or accurately in field testing because of insufficient traction or high speeds. The calculations are based on the measured pull in a lower gear at a specific engine speed, the overall gear ratios in the ranges being considered, and the measured resistances to towing (ref TOP 2-2-605[7]) at the road speeds. On this basis and at the same engine speed, the approximate DBP is computed using the following formulas:

Computing for higher gear:

$$DBP_2 = \left(DBP_1 + R_1\right)\frac{OGR_2}{OGR_1} - R_2$$

Computing for lower gear:

$$DBP_1 = \left(DBP_2 + R_2\right)\frac{OGR_1}{OGR_2} - R_1$$

Where:

DBP_1 = Drawbar pull (kN or lb) in lower gear
DBP_2 = Drawbar pull (kN or lb) in higher gear
R_1 = Resistance to tow (kN or lb) at road speed* for DBP_1
R_2 = Resistance to tow (kN or lb) at road speed* for DBP_2
OGR_1 = Overall gear ratio for lower gear
OGR_2 = Overall gear ratio for higher gear

*Road speed for the unknown *DBP* value is computed using one of the following formulas:

$$S_1 = S_2\left(\frac{OGR_1}{OGR_2}\right)$$

$$S_2 = S_1\left(\frac{OGR_2}{OGR_1}\right)$$

Where:

S1 = Speed for lower gear
S2 = Speed for higher gear
OGR_1 = Overall gear ratio for lower gear
OGR_2 = Overall gear ratio for higher gear

Similar DBP calculations can be made for torque converter type transmissions using converter speed ratios.

b. For vehicles with any type of fluid coupling (e.g., torque converter), the maximum pull in the lowest gear range under conditions of vehicle stall (i.e. no forward motion) may be required. For tracked vehicles, it may be necessary, at times, to tie down the tracks of the test vehicle to obtain this pull without loss of traction. Maximum pull may also be obtained by measuring the stall pull in a higher gear and then computing the lower gear value as follows:

$$DBP_1 = DBP_2\left(\frac{OGR_1}{OGR_2}\right)$$

c. Special consideration should be given to vehicles with electronically-controlled automatic transmissions as they are likely to have some type of shift algorithm integrated into the transmission shift control module to protect the drive line from damage. When attempting to test at certain gear ranges and engine/flywheel speeds, the electronic shift control may command the transmission to upshift or downshift to adjust the torque distribution amongst drive line components or to keep the engine speed and rotational speed of drive line components in safe operating ranges. If DBP at a certain gear range is desired, arrangements should be made with the manufacturer on how to command the transmission to select and remain in the desired gear range.

d. With automatic transmissions incorporating a torque converter, attention should be directed at transmission fluid temperatures and the point at which torque converter “lockup” is achieved. Lockup of the torque converter is achieved when the ratio of transmission input speed to engine output speed becomes 1:1. Before lockup is achieved, the transmission fluid temperatures will be greater because the fluid is acting as the coupling between the torque converter plates. When lockup is achieved, the plates are mechanically locked, and the fluid coupling is no longer needed. Torque converter lockup almost always occurs when the drive line is subjected to the lowest torque demands and will cease when a greater torque load is experienced. Depending on application, torque multiplication by the converter may occur only in certain gear ranges.

4.2 Drawbar Pull on Hard Surface.

Method. Conduct this test with the test vehicle towing a mobile, field dynamometer by means of an instrumented drawbar over a dry, clean, level, hard surface. Road speed is measured by use of an instrumented fifth wheel device attached to the test vehicle. Wheel or track-sprocket speed is also measured and recorded for use in computing the percentage of slip. Measurements are made at sufficient increments of road speed, including vehicle stall when possible, to delineate performance curves and to provide an evaluation of full-load fuel consumption (TOP 2-2-603[4]). Speeds in each gear must be chosen so that the data has an overlap of speed from one gear to the next. Engine and transmission oil and cooling system pressures and temperatures are recorded, if required. A run is considered valid when engine temperatures are not changing significantly (less than 1.1˚C (2˚F) per minute) and a speed is held long enough so that steady conditions are obtained and recorded. Runs require a stabilized drawbar pull and speed, and must be at least 30 seconds in duration, in both directions on the course.

Values for track or wheel slippage are obtained through computations using the test data and the following formulas:

$$\text{Percent Slip} = \frac{C - A}{C} \text{ X } 100$$

Where:

A = Actual vehicle road speed in mph
C = Computed theoretical or no-slip road speed in mph

C can be computed by the following formula:

$$C = (WS)\,(d)\left(\frac{1}{88}\right)$$

Where:

C = Computed theoretical or no-slip road speed in mph
WS = Wheel or sprocket speed in rpm
d = Rolling distance of one revolution of wheel or sprocket in ft/rev

NOTE: For metric units, use km/hr instead of mph, m/rev instead of ft/rev, and $\left(\frac{1}{16.7}\right)$ instead of $\left(\frac{1}{88}\right)$.

Values for drawbar power are obtained through computations using the test data and the following formula:

$$DBPower = \frac{(S)(DBP)}{375}$$

Where:

DBPower = Drawbar power in horsepower
S = road speed in mph
DBP = Drawbar pull force in lb

NOTE: For metric units, use km/hr instead of mph, kN instead lb, and 3.6 instead of 375 to give drawbar power in kW.

4.3 Drawbar Pull in Soft Soil.

Method. Conduct this test in the same manner as the hard surface drawbar pull test except that the mobile field dynamometer or other suitable vehicle is towed over level, soft soil tilled to a specified depth or is used to retard motion on a mud surface. The soil condition is determined and recorded as described in TOP/MTP 2-2-619[8], ITOP 2-2-619(1)[6], and ITOP 2-2-604(1)[9]. Drawbar pull and engine speed are recorded for vehicle stall and other various speeds on soft soils.

4.4 Amphibious Vehicle Tests (Drawbar Pull in Water and Bollard Pull).

These tests are also applicable to various other watercrafts as described in TOP 9-2-251[10].

Method.

a. Drawbar Pull in Water.

Measure drawbar pull for amphibious vehicles at various speeds in water by towing a boat (or another amphibious vehicle) in reverse propulsion to the extent necessary for "loading" the test vehicle at the various test vehicle speeds. The load measuring device is connected between the two vehicles. The towed item is thus comparable with the dynamometer "load" towed by wheeled or tracked vehicles on land. Care must be exercised to insure that the depth of water is sufficient to give true values (ref TOP 2-2-501[11]). Drawbar pull, engine speed, and propellant-device speed are recorded for vehicle stall and for various speeds in water.

b. Bollard Pull.

This test is similar to the drawbar pull in water, but is conducted by pulling against a fixed object. Conduct this test in water with the floating vehicle moored to a bollard or some other rigid shore structure. The mooring line includes a load measuring device and is located directly above and horizontally in line with the propeller shaft or line of thrust.

If the vehicle has rudders, set them on center. Engines are operated in forward gear for five minutes at each increment of engine speed up to and including the maximum engine rpm. Gage and instrument readings are taken, including engine and transmission oil and cooling system pressures and temperatures at the end of each engine-speed period. A record is kept of gage and instrument readings, and load readings, at each specified engine speed.

For multiple-propulsor amphibious vehicles, each propulsor should be tested independently with the mooring line directly above and horizontally in line with the line of thrust of each propulsor.

5. DATA REQUIRED.

5.1 Data Required (Hard Surface).

a. Engine speed

b. Vehicle speed

c. Drawbar pull

d. Fuel temperature (entering the engine)

e. Fuel consumption

f. Critical component pressures and temperatures

g. Gear range

h. Torque converter lockup

i. Wheel slip

j. Tire pressures

k. Meteorological data (temperature, humidity, wind speed/direction, and barometric pressure)

l. Calculated values for track or wheel slippage

m. Calculated values for drawbar power

5.2 Data Required (Soft Soil).

a. Cone pentrometer reading (cone index)

b. Percent soil moisture content

c. Soil density

d. Soil depth (to hardpan)

e. Vehicle penetration

f. Depth of tilling

g. Soil type – Unified Soil Classification System

h. Tire pressure

i. Engine speed

j. Vehicle speed

k. Drawbar pull

l. Fuel temperature (entering the engine)

m. Fuel consumption

n. Critical component pressures and temperatures

o. Gear range

p. Torque converter lockup

q. Meteorological data (temperature, humidity, wind speed/direction, and barometric pressure)

5.3 Amphibious Vehicles.

a. Load values

b. Engine speed

c. Propulsion device speed

d. Water temperature

e. Gear range

f. Propulsion specifications

g. Meteorological data (temperature, humidity, wind speed/direction, and barometric pressure)

h. Water depth

i. Fuel temperature (entering the engine)

j. Fuel consumption

k. Critical component pressures and temperatures

6. DATA PRESENTATION.

Example data presentation curves for drawbar pull and drawbar power are presented in Figures 1 and 2.

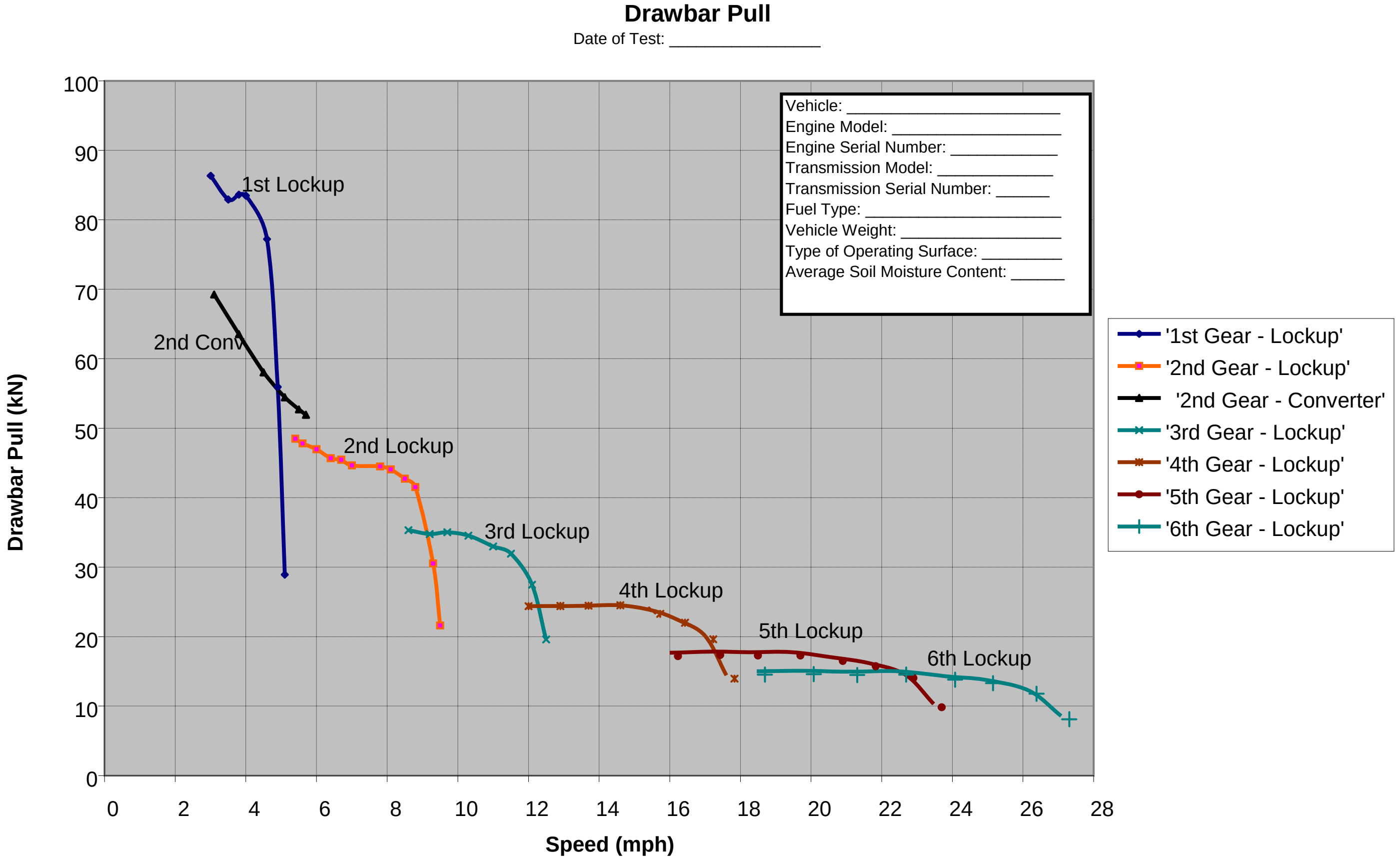

FIGURE 1. Drawbar pull characteristics

Vehicle: ______________________________
Engine Model: ___________________________
Engine Serial Number: ____________________
Transmission Model: _____________________
Transmission Serial Number: ______________
Fuel Type: ______________________________
Vehicle Weight: __________________________
Type of Operating Surface: ________________
Average Soil Moisture Content:

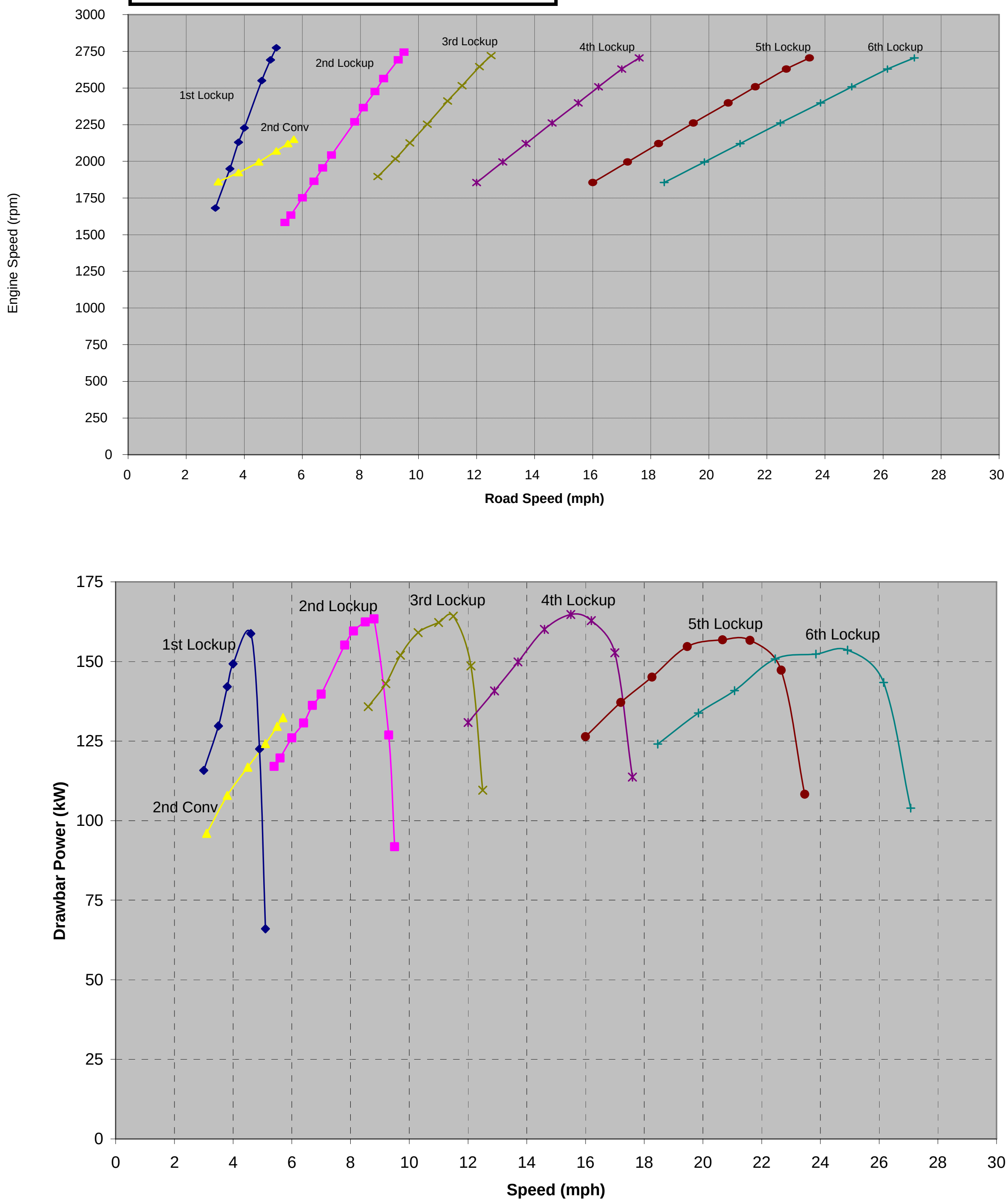

FIGURE 2. Drawbar power characteristics

6.1 Data Required

Curves (as shown in Figures 1 and 2) similar to those used to present hard surface test results (ref Paragraph 5.1). An example of drawbar pull versus slip is shown in Figure 3.

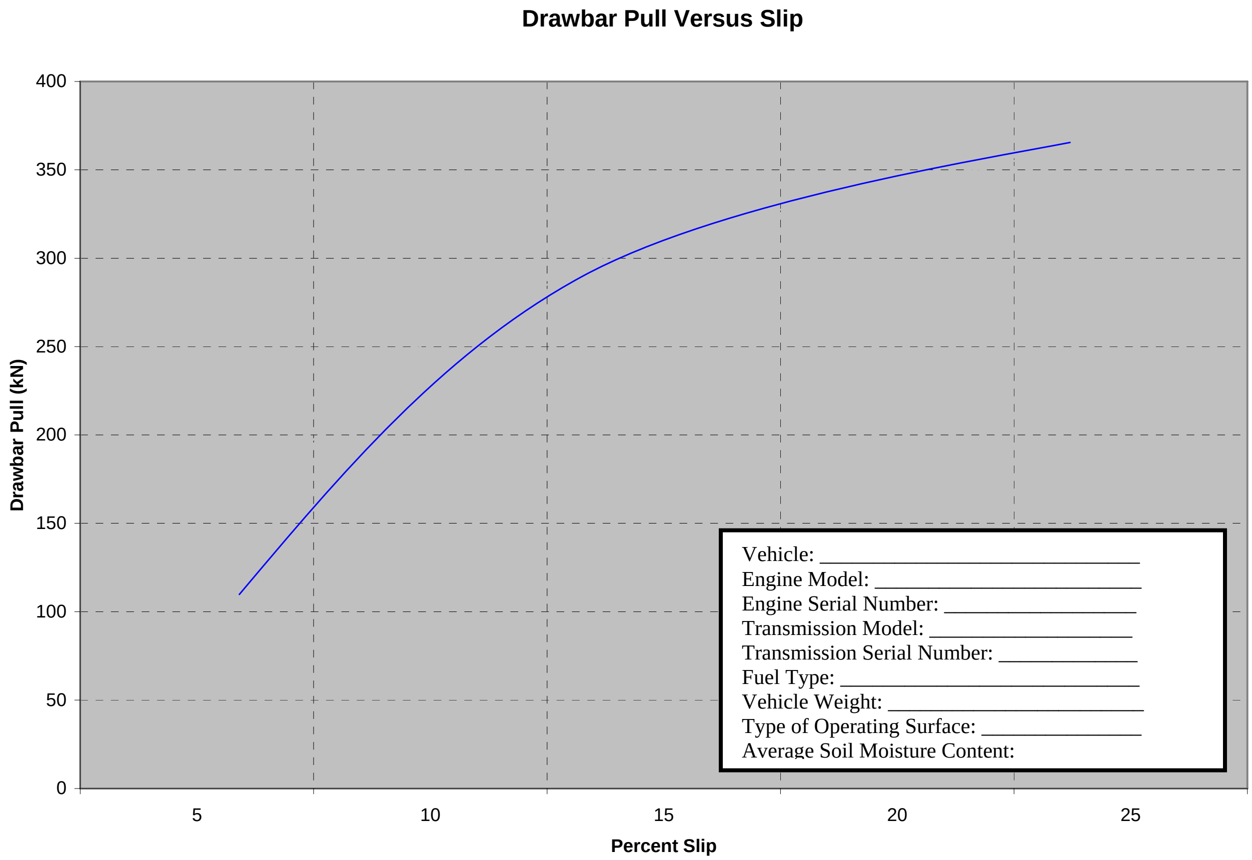

FIGURE 3. Drawbar pull versus slip

6.2 Amphibious Vehicles

Data are presented as a graph drawbar load versus engine speed for amphibious vehicles as shown in Figure 4. If the vehicle is equipped with a multi-range transmission, plots of each gear range should be presented.

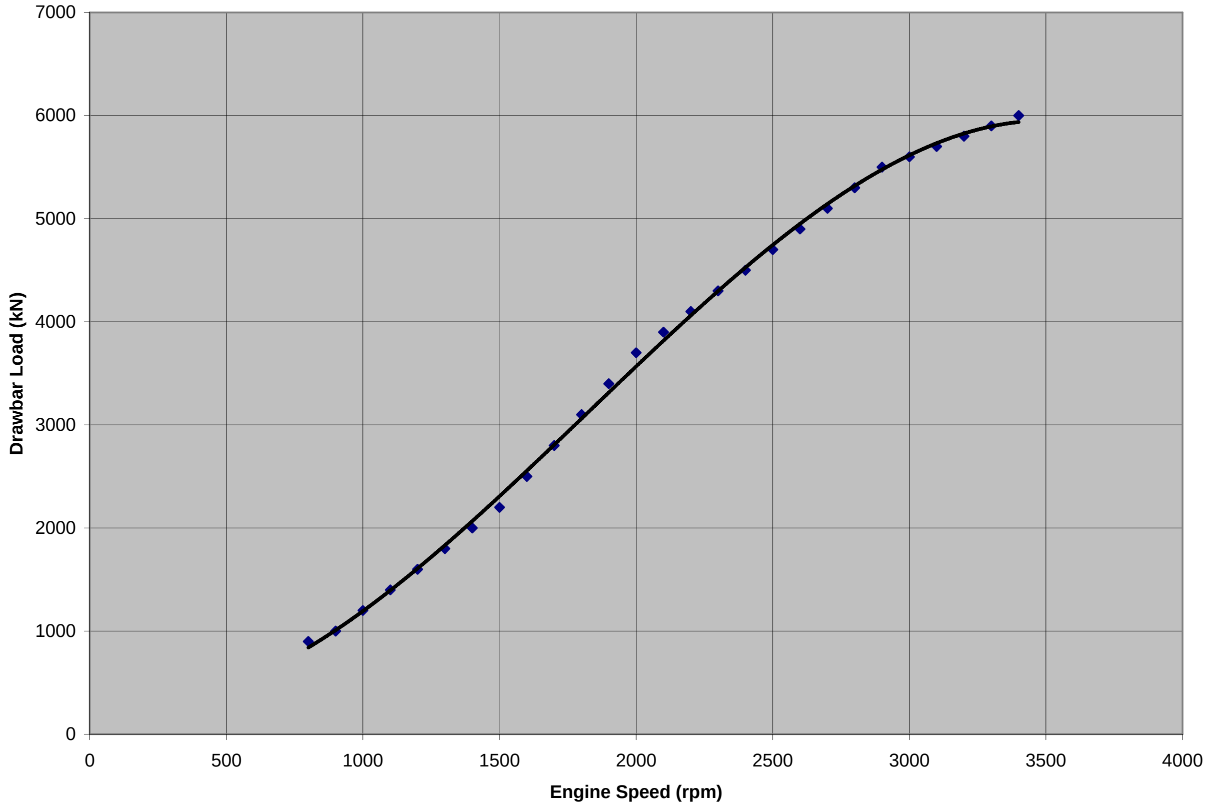

FIGURE 4. Water drawbar pull or bollard pull characteristics

APPENDIX A. ABBREVIATIONS

cm	-	centimeters
DBP	-	Drawbar pull
DTP	-	Detailed Test Plan
FM	-	Field Manual
Hg	-	Mercury
hPa/mb	-	hectopascals, millibar
IAW	-	In accordance with
ITOP	-	International Test Operations Procedure
km/hr	-	kilometers per hour
kts	-	knots
m/s	-	meters per second
MTP	-	Materiel Test Procedure
SOP	-	Standard Operating Procedure
TM	-	Technical Manual
TOP	-	Test Operations Procedure

APPENDIX B. REFERENCES

1. TOP 2-2-610, Gradeability and Side-Slope Performance, 18 July 1980.

2. TOP 2-1-005, Automotive Field Test Equipment and Instrument, 4 April 1989.

3. Test Operating Procedure (TOP) 2-2-500, Vehicle Characteristics, 3 December 1981.

4. TOP 2-2-603, Vehicle Fuel Consumption w/Change 1, 4 February 1986.

5. Field Manual (FM) 5-430-00-1, Planning and Design of Roads, Airfields, and Heliports in the Theater of Operations – Road Design, 26 August 1994.

6. International Test Operating Procedure (ITOP) 2-2-619(1), Tracked-Vehicle Soft-Soil Mobility, 1 June 1987.

7. TOP 2-2-605, Wheeled Vehicle Towing Resistance, 29 July 1993.

8. TOP/Materiel Test Procedure (MTP) 2-2-619, Soft-Soil Vehicle Mobility, 21 May 1970.

9. ITOP 2-2-604(1), Tracked Vehicle – Drawbar Pull on Soft Soil w/Change 1, 11 August 1987.

10. TOP 9-2-251, Waterway Equipment Boat, Barge, Motor, 18 August 1972.

11. TOP 2-2-501, Rail Impact Testing, 30 June 1995.

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 (CSTE-DTC-TM-B), U.S. Army Developmental Test Command, 314 Longs Corner Road, Aberdeen Proving Ground, MD 21005-5055. Technical information may be obtained from the preparing activity: Combat and Automotive Systems Division (CSTE-DTC-YP-YT-CA), U.S. Army Yuma Proving Ground, 301 C. Street, Yuma, AZ 85365-9498. Additional copies are available from the Defense Technical Information Center, 8725 John J. Kingman Rd., Suite 0944, Fort Belvoir, VA 22060-6218. This document is identified by the accession number (AD No.) printed on the first page.