# Vehicle Performance Testing

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## Introduction

This report will describe some simple testing to determine the performance of a wheeled vehicle. These tests will lead to measuring the horsepower developed by the engine. No elaborate instrumentation is required to collect the data from these tests. The calculations required to reach the engine horsepower are outlined in this report. This report also contains the test procedures to conduct the tests.

The equations used by these test are explained in detail in “The Science of Vehicle Performance” report. To simplify these tests, a few assumptions must be made. The first assumption is that there is perfect traction between the drive tires and the contact surface. The second assumption is that the tests take place on a hard, smooth, level surface. The final assumption is that the tests are conducted at sea level on a standard day on planet Earth. This final assumption allows the use of several physical constants in the calculations that are valid only for this planet. It should also be noted that the final horsepower is for the conditions of the test day.

The tests described in this report are basically the same test. The differences in these tests involve the speeds at which the tests are conducted and whether the engine is being used. The first two tests are used to determine the losses or where the engine horsepower is being used. These tests are called coast down tests and are performed without power from the engine. The third test is an acceleration test at maximum throttle which will determines the engine horsepower.

## Summary of Equations

These test actually require only a few equations for data reduction. All of these equations are to fill the pieces of the equation for Newton's second law of motion:

$$\sum F = ma \qquad \text{(equation 1)}$$

Where:

$\Sigma F$ is the sum of the forces in pounds
m is the mass of the object in slug per cubic feet
a is the acceleration in feet per second squared

The mass of the test vehicle is defines as the weight divided by the gravitational constant, 32.2 feet per second:

$$m = \frac{W}{32.2} \qquad \text{(equation 2)}$$

The acceleration in this equation is the value that will be measured during the tests. This value is calculated from the speed, in MPH, and time, in seconds, collected during the test with the following equation:

$$a = 1.467\left(\frac{MPH_2 - MPH_1}{t_2 - t_1}\right) \qquad \text{(equation 3)}$$

Where:

a is the acceleration in feet per second squared
$MPH_2$ is the ending speed in miles per hour
$MPH_1$ is the initial speed in miles per hour
$t_2$ is ending time in seconds
$t_1$ is initial time in seconds

From these equations the mass times acceleration is:

$$ma = \frac{W}{21.95}\left(\frac{MPH_2 - MPH_1}{t_2 - t_1}\right) \qquad \text{(equation 4)}$$

The forces in Newton's second law of motion are the thrust at the drive wheels, rolling friction and aerodynamic drag. The thrust at the drive wheels is calculated from the horsepower at the engine flywheel with the following equation:

$$T_{wheels} = \frac{375\ \eta\ HP_{flywheel}}{MPH} \qquad \text{(equation 5)}$$

Where:

$T_{wheels}$ is the thrust available at the drive wheels in pounds

$\eta$ (eta) is the drivetrain efficiency

$HP_{flywheel}$ is the horsepower at the engine flywheel

MPH is the average vehicle speed during the time period $(MPH_2+MPH_1)/2$

The rolling resistance is determined from the following equation:

$$R = \mu\,(W - L) \qquad \text{(equation 6)}$$

Where:

R is the in pounds

$\mu$ (mu) is the coefficient of rolling friction

W is the vehicle weight in pounds.

L is aerodynamic lift in pounds.

This equation has a term for aerodynamic lift. This term is typically small and can be estimated or ignored if the value is not known. A reasonable estimate for this term can be calculated from the following equation with a $C_L$ value of 0.3:

$$L = 0.002558\ C_L S_{ref} MPH^2 \qquad \text{(equation 7)}$$

Where:

L is aerodynamic lift in pounds.

$C_L$ is the drag coefficient.

$S_{ref}$ is a reference area in square feet

MPH is the average vehicle speed during the time period $(MPH_2+MPH_1)/2$

The final force considered in these test is aerodynamic drag. This force is calculated from the following equation:

$$D = 0.002558\ C_D S_{ref} MPH^2 \qquad \text{(equation 8)}$$

Where:

D is aerodynamic drag in pounds.

$C_D$ is the drag coefficient.

$S_{ref}$ is a reference area in square feet

MPH is the average vehicle speed during the time period $(MPH_2+MPH_1)/2$

Using all of these equations, Newton's second law of motion becomes:

$$\sum F = \frac{375\ \eta\ HP_{flywheel}}{MPH} - \mu\left(W - 0.002558\ C_L S_{ref} MPH^2\right) - 0.002558\ C_D S_{ref} MPH^2 = \frac{W}{21.95}\left(\frac{MPH_2 - MPH_1}{t_2 - t_1}\right) \qquad \text{(equation 9)}$$

The horsepower at the engine flywheel will be determined from the test results. Since horsepower is traditionally expressed for a range of RPM, a conversion between MPH and RPM is needed. This conversion is the following equation:

$$MPH = \frac{d_{tire}}{336.1\ G_{trans} G_{diff}} RPM \qquad \text{(equation 10)}$$

Where:

$d_{tire}$ is the tire diameter in inches
$G_{trans}$ is the transmission gearing
$G_{diff}$ is the differential gearing

The final equation allows for the conversion between horsepower and torque. This equation is:

$$Horsepower = \frac{RPM}{5252} Torque \qquad \text{(equation 11)}$$

## Performance Tests

The performance of a vehicle can be measured using the equations discussed in this report. These tests will measure the forces due to rolling friction and aerodynamic drag as well as the horsepower output of the engine. The Appendix of this report contains the detailed test procedures and data collection sheets to aid in the completion of these tests.

Since these tests involve a moving vehicle, safety must be a primary concern. The test area should be relatively free of traffic. The act of data collection involves recording speed and time. For safety, it is recommended that the test be accomplished by two people in the vehicle, one to be the driver and one to record the data. The primary task of the driver of the vehicle is the safe operation of the vehicle during the test. One of the tests involves accelerating at maximum throttle. During this test the engine is operating at maximum power and the vehicle will be accelerating at maximum capability. During this test, extra attention to safety must be taken, as well as consideration of local traffic laws.

These tests require a relatively flat smooth surface to minimize the effects of gravity on acceleration. The aerodynamic forces are affected by with speed of the wind as well as the speed of the car. The tests should be conducted when the wind is calm. If the wind is not calm, the test should be repeated in the opposite direction. The accuracy of the instruments used to collect the data during the test directly affects the accuracy of the results. The frequency that the data is recorded during the test will also improve accuracy.

The performance tests discussed are three variations of an acceleration test. The data collected for the tests are vehicle weight, speed and time. Vehicle weight can be determined by several methods. The simplest method would be to find vehicle weight in manufacturer documentation. This weight may not reflect the actual weight of the test vehicle. The best method would be to actually weight the test vehicle. Scales to weigh vehicles can be found at most recycling facilities. Another method would be to use a set of corner scales.

Speed and time are to be recorded during the test. This data should be collected by the driver calling off predetermined speeds and an assistant recording the time from the start of the test. This can be done with both people in the vehicle or with the driver making the calls over a radio and the assistant recording the data outside of the car. Other methods may be considered. The only option that should not be considered would involve the driver recording the data, as this would not be safe.

The instrumentation to measure speed can be from several sources. The most obvious would be the speedometer. The accuracy of the speedometer will affect the accuracy of the test results in two ways: the accuracy of the instrument and the accuracy the reading. The typical speedometer should be accurate enough for most applications of these tests. If the vehicle is not equipped with a speedometer speed can still be measured. An add-on device, such as GPS, can be used to measure the speed. Distances along the test course can be marked. During the test the distance markers would be noted and with the time to reach that point, the speed can be determined.

The instrumentation to measure time can be as simple as a wristwatch with a second hand. A relatively inexpensive digital stopwatch with the capability to record several points or lap times would be a good choice for these tests.

Three variations of an acceleration test are considered. Two of the tests are decelerating and one test is accelerating. The equation for Newton's second law of motion, equation 9, will be used to find the test objective. Some terms in this equation are not used for some tests. The tests build on each other, that is the results from the first test are used in the second test and so on.

The first test is a low speed coast down test. The objective of this test is to measure the coefficient rolling resistance of the test vehicle. To accomplish this, the terms in equation 9 for thrust at the drive wheels and aerodynamic drag are not used. The thrust at the drive wheels is removed by not using the engine. This is done by placing the transmission in neutral after the test is set up. The speeds for this test are selected to minimize the aerodynamic drag. A typical starting speed would be less than 40 MPH. Since the speeds are low enough to minimize aerodynamic drag, the aerodynamic lift will also be minimized. With these restrictions on Newton's second law of motion, equation 9 and solving for the coefficient of rolling friction, the equation for the coefficient of rolling friction is:

$$\mu = -0.0456 \frac{MPH_2 - MPH_1}{t_2 - t_1} \qquad \text{(equation 12)}$$

Since the speeds are decreasing during this test, the value of $MPH_2$-$MPH_1$ will be less than zero and therefore the coefficient of rolling friction will be a number greater than 0. This equation is used to calculate the coefficient of rolling friction for each time period. The overall coefficient of rolling friction for the test vehicle is calculated from the average of these values. This average value will be used to find the objectives for other tests.

The second test is also a coast down test, however this test is conducted at higher speeds. The purpose of this test is to determine the drag coefficient of the test vehicle. The starting speed for this test should be as high as conditions permit. This test can be repeated with different starting speed so that the overall speed range extends to the initial speed of the first test. The value of the coefficient of rolling friction for the test vehicle is required for the data reduction of this test. The configuration of the test vehicle should be consistent with the test that determined the coefficient of rolling friction. The higher speeds of this test increase the contribution due to aerodynamic lift. As with the first test, the thrust at the drive wheels is not included. Using Newton's second law of motion, equation 9, and solving for the drag coefficient, the equation becomes:

$$C_D = \mu\, C_L - \frac{W}{S_{ref}\, MPH^2}\left[17.81\, \frac{MPH_2 - MPH_1}{t_2 - t_1} + 391\, \mu\right] \quad \text{(equation 13)}$$

The final test is a maximum acceleration. The purpose of this test is to determine the horsepower at the engine flywheel. This test begins at a constant speed. The final speed does not have to the maximum speed of the vehicle. This test should include the entire range of engine RPM through at least one transmission gear. The use of maximum throttle is critical to this test. However, the tires should not be allowed to spin on the ground. Once again, the equation for Newton's second law of motion is used to find the horsepower at the flywheel with the following equation:

$$HP_{flywheel} = \frac{W\, MPH}{\eta}\left[0.001215\, \frac{MPH_2 - MPH_1}{t_2 - t_1} + \frac{\mu}{375}\right] + \frac{S_{ref}\, MPH^3}{146600\, \eta}\left[C_D + \mu\, C_L\right] \quad \text{(equation 14)}$$

## Low Speed Coast Down Test Procedure

The purpose of this test is to determine the rolling resistance and the coefficient of rolling friction for the test vehicle. The test should be conducted over a straight course with a smooth, flat surface. The course should have little or no other traffic that may interfere with the test. The initial speed should be less than 40 MPH for this test. It is recommended that the test be repeated in the opposite direction over the course to reduce the effect of any slope in the course.

The following steps outline the process to conduct the test and collect the necessary data for a typical test vehicle.

1. Set up the test vehicle at speed slightly greater than the initial test speed.
2. Disengage the engine by placing the transmission in neutral.
3. Allow the vehicle to reduce speed without any braking inputs.
4. Begin timing when the initial speed is reached. Record this speed.
5. Record time and speed as the vehicle continues to slow without braking.
6. Repeat step 5 for several speeds and times until the final speed is reached.

## Coast Down Test Procedure

The purpose of this test is to determine the aerodynamic drag force and the drag coefficient for the test vehicle. The test should be conducted over a straight course with a smooth, flat surface. The course should have little or no other traffic that may interfere with the test. The initial speed should be as high as local traffic laws permit. It is recommended that the test be repeated in the opposite direction over the course to reduce the effect of any slope in the course.

The following steps outline the process to conduct the test and collect the necessary data for a typical test vehicle.

1. Set up the test vehicle at speed slightly greater than the initial test speed.
2. Disengage the engine by placing the transmission in neutral.
3. Allow the vehicle to reduce speed without any braking inputs.
4. Begin timing when the initial speed is reached. Record this speed.
5. Record time and speed as the vehicle continues to slow without braking.
6. Repeat step 5 for several speeds and times until the final speed is reached.

## Maximum Acceleration Test Procedure

The purpose of this test is to determine the engine horsepower and torque for the test vehicle. The test should be conducted over a straight course with a smooth, flat surface. The course should have little or no other traffic that may interfere with the test. The test does not have to begin from a standing start and the ending speed does not have to be the maximum speed of the test vehicle. The test should cover then entire range of engine RPM for at least one gear of the transmission. It is recommended that the test be repeated in the opposite direction over the course to reduce the effect of any slope in the course.

The following steps outline the process to conduct the test and collect the necessary data for a typical test vehicle.

1. Set up the test vehicle at a speed slight slower than the initial test speed.
2. Accelerate at maximum throttle.
3. Begin timing when the initial speed is reached. Record this speed.
4. Record time and speed as the vehicle continues to slow without braking.
5. Repeat step 4 for several speeds and times until the final speed is reached.

## Test Data Reduction

This process can be completed with paper and pencil or a computer. Excel spreadsheets are included with this report that will automate this data reduction process and provide detailed output from the test. Since the data reduction involves calculating the difference between the data points, one point will not have calculated values. For the coast down tests, the first calculated values correspond to the second data point. For the acceleration test, the last data point in each gear does not have a calculated value. The final values from the two coast down tests are determined from the average of the values calculated for each time interval. The data reduction outlined below is a simplified method that only calculates the value that is the test objective.

1. Calculate the change in speed between two consecutive data points by subtracting the first speed from the second. ($MPH_2$-$MPH_1$).
   a. This value should be less than zero for the coast down tests.
2. Calculate the change in time between two consecutive data points by subtracting the first time from the second ($t_2$-$t_1$).
3. Calculate the objective of the test by using the equation for the test
   a. Use equation 12 to calculate the coefficient of rolling friction for the low speed coast down test
   b. Use equation 13 to calculate the aerodynamic drag coefficient for the coast down test.
   c. Use equation 14 to calculate the horsepower at the engine flywheel for the maximum acceleration test. For this test MPH should be converted to RPM by using equation 10.

## Appendix A: Data Collection Sheet

This page can be used in the collection of time and speed data during the acceleration tests.

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