The Science of Vehicle Performance

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1 Introduction

Science can be used to understand and explain how vehicles perform. The science used primarily comes from the laws of Physics. These laws define how an object moves. These laws can be used to determine many aspects of vehicle performance. Questions about performance such as; what is the maximum speed? How effective will a modification be? What is the best time to shift? All of these questions and more can be answered by using science.

This report will discuss the topics of vehicle performance as they relate to a piston engine powered wheeled vehicle. The science used in this report is used in a subsequent report on testing vehicle performance. The examples in this report are based on a 1966 Chevrolet Corvair.

2 Mechanical Relationships

Several mechanical relationships must be established before exploring the science of vehicle performance. These relationships involve unit conversions between standards of piston engines and aspects of geometry in mechanical devices.

2.1 Horsepower

The power output of a piston engine is typically expressed in terms of horsepower and torque over a range of engine RPM. These values are essentially different ways to express the same quantity. Horsepower and torque are related through the following equation:

$$\mathbf{Horsepower} = \frac{\mathbf{RPM}}{\mathbf{5252}}\mathbf{Torque} \qquad \text{(equation 2-1)}$$

The horsepower generated by the engine is transferred to the ground though the tires, transmission and differential. This combination, with the associated shafts and bearings, is referred to as the drivetrain. These mechanical devices use some of the engine power to rotate. The power used by the drivetrain is proportional to the rotational speed. This power is commonly expressed as a ratio to the power generated by the engine. This ratio is the drivetrain efficiency. This efficiency can be measured by dynamometer tests of the engine alone and installed in the vehicle. A typical value of drivetrain efficiency is 0.85 for mass produced vehicles. The horsepower available at the drive wheels is related to the horsepower at the engine flywheel through this equation:

$$HP_{wheels} = \eta \, HP_{flywheel} \qquad \text{(equation 2-2)}$$

Where:

HP_{wheels} is the horsepower at the wheels

η (eta) is the drivetrain efficiency

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

2.2 Gearing

The transmission and differential are mechanical devices that change RPM. This is required to deliver the necessary power to drive wheels for the driving conditions. Typically this is done though a series of gears, however there are other methods employed in different types of these devices. The ratio of RPM from the input side to output side of a device is referred to as the gearing. This ratio is typically a ratio to 1, as in 3.55 to 1, or just the first number, 3.55. If the gearing is greater than 1 then the output is turning slower than input, and when the gearing is less than 1, the output is turning faster than the input. This means that the input shaft turns 3.55 revolutions for one revolution of the output shaft. The gearing determines the relationship between engine RPM and vehicle speed with the overall size of the drive tire. With unit conversions, the equation for the relationship between MPH to RPM is:

$$\mathbf{MPH} = \frac{\mathbf{d_{tire}}}{\mathbf{336.1\,G_{trans}\,G_{diff}}}\mathbf{RPM} \qquad \text{(equation 2-3)}$$

Where:

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

3 Science of Physics

3.1 Kinematic Equations of Motion

The kinematic equations of motion relate the motion of an object in terms of time, distance, speed and acceleration. These equations are valid when the acceleration of the object is constant between the initial and final conditions. For analysis if vehicle performance, the acceleration can be considered constant over small time intervals. The kinematic equations of motion are:

$$a = \frac{v_f - v_i}{t_f - t_i} \qquad x = x_o + \frac{1}{2}(v_i + v_f)t \qquad \text{(equations 3-1, 3-2)}$$

$$v_f = v_i + a\,t \qquad x = x_o + v_i + \frac{1}{2}a\ t^2 \qquad \text{(equations 3-3, 3-4)}$$

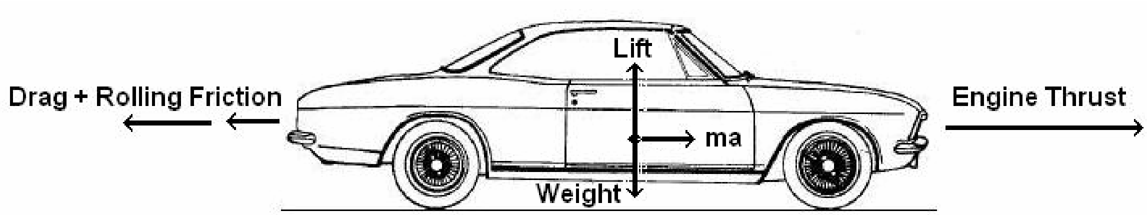
Where:

- a is the acceleration in feet per second squared
- v_f is the final speed in feet per second
- v_i is the initial speed in feet per second
- t_f is final time in seconds
- t_i is initial time in seconds

3.2 Newton's Laws of Motion

Newton's laws of motion describe the causes of an objects motion. Newton's first law states that to move an object a force must be applied to that object and once an object is moving a force is required to change that motion. The force that is applied to start moving or accelerate a vehicle comes from the engine. The force to slow a vehicle comes from the brakes or another resistive force. Newton's second law of motion describes the amount of force that is required. The second law can be summarized as the sum of the forces acting on an object is equal to the object's mass times acceleration. Newton's third law of motion states that for every action there is a reaction. In the case of a moving vehicle, the engine generates a force at the drive wheels, which is exerted on the road, which provides a reactive force to the vehicle, which moves the vehicle.

Newton's second law will be investigated further to describe vehicle performance. The forces acting on the vehicle include the forces from engine power, rolling friction, aerodynamic drag and a force from weight if the vehicle is moving up or down a hill. The following diagram illustrates the forces acting on a vehicle:



Newton's second law is expressed in the following equation:

$$\sum F = T_{wheels} - R - D = m \times a \qquad \text{(equation 3-5)}$$

Where:

ΣF is the sum of the forces in pounds
T_{wheels} is the thrust available at the drive wheels in pounds
R is the force due to rolling friction in pounds
D is the aerodynamic drag in pounds
m is the mass of the object in slug per cubic feet
a is the acceleration in feet per second squared

The acceleration in this equation is equal to the acceleration in the kinematic equations of motion. Using the kinematic equation for acceleration and converting the speeds to MPH, the equation for acceleration becomes:

$$a = 1.467\left(\frac{MPH_2 - MPH_1}{t_2 - t_1}\right) \qquad \text{(equation 3-6)}$$

3.3 Power

The engine thrust originates from the power output of the engine. Since the output from the engine is given as power, a relationship between force and power is needed. Power is defined as the amount of work done for a period of time. Work is defined as a force acting over a distance. Power can be expressed as a force acting over a distance for a period of time. In mathematical terms the equation for power in terms of force is:

$$Power = Thrust \times Speed \qquad \text{(equation 3-5)}$$

The basic English unit for power is foot - pounds per second. James Watt, a Scottish inventor, made up the unit of measure for power that is commonly used to describe the power output of an engine. Mr. Watt wanted a measure of power to help sell steam engines. Since the steam engines were replacing horses as a power source, he wanted to use this standard horse for the basis of his power unit. He observed horses used to grind wheat into flour and estimated that a horse could pull 550 pounds 1 foot in 1 second. Using this information as well as a conversion for speed, the thrust from the engine can be expressed as:

$$T_{wheels} = \frac{374.5 \times HP_{wheels}}{MPH} \qquad \text{(equation 3-6)}$$

Where:

T is the engine thrust in pounds
HP is horsepower

The thrust from the engine is applied at the drive wheels. The engine horsepower is provided at the engine flywheel. In the Mechanical Relationship section of this report, an equation for the horsepower available at the wheels was defined in terms of the horsepower at the engine flywheel (equation 2-2). This relationship is used in the above equation, which results in the equation for engine thrust in terms of horsepower at the flywheel as:

$$T_{wheels} = \frac{374.5 \times \eta \times HP_{flywheels}}{MPH} \qquad \text{(equation 3-7)}$$

3.4 Friction

The force due to rolling friction is due tires being in contact with the ground and the wheel bearings. This is the force required to move the vehicle at low speed. This force depends on the inflation of the tire, material of the tire, how much the tire deforms, the adhesion between the tire and the road, and the condition of the bearings. The law of friction states that the force is proportional to the load carried. The equation for rolling friction is:

$$R = \mu (W - L) \qquad \text{(equation 3-8)}$$

Where:

R is the in pounds

μ (mu) is the coefficient of rolling friction

W is the vehicle weight in pounds.

L is aerodynamic lift in pounds.

This force is not dependant on the area of the tire in contact with the surface. The value of the coefficient of rolling friction depends on characteristics of the tire and the surface of the road. Typical values of the coefficient of rolling friction vary from 0.015 to 0.06. A simple test to measure the coefficient of rolling friction is described in the testing report.

4 Basic Aerodynamics

Aerodynamics is the study of the effects of a moving fluid or gas on a body. The air flowing around, through and under the vehicle generates forces and moments on the vehicle. These forces and moments are based on the shape of the vehicle, the speed of the air and the characteristics of the air.

Several methods exist to predict aerodynamic forces and moments. These methods can be simple to extremely complex and have varying levels of accuracy. The best method of determining the aerodynamic characteristics of a vehicle is to perform wind tunnel tests. Wind tunnel test are performed on a model of the vehicle or an actual vehicle depending in the size of the wind tunnel. The vehicle is connected to instrumentation that measures the aerodynamic forces and moments. This data is enables the determination of the aerodynamic coefficients for the vehicle.

Aerodynamic coefficients represent the forces and moments without the effect of specific conditions of the air. These coefficients still vary with other conditions such as speed and attitude of the vehicle. However, for most ground-based vehicles, the aerodynamic coefficients can be considered constants. A reference area is also used to the aerodynamic coefficients. The reference area for vehicles is typically the maximum frontal cross sectional area. The aerodynamic lift and drag are the forces of most concern to vehicle performance. These forces are calculated from the following equations:

$$\mathbf{L} = \mathbf{C_L} \times \mathbf{S_{ref}} \times \frac{1}{2} \rho \, \mathbf{V}^2 \qquad \text{(equation 4-1)}$$

$$\mathbf{D} = \mathbf{C_D} \times \mathbf{S_{ref}} \times \frac{1}{2} \rho \, \mathbf{V}^2 \qquad \text{(equation 4-2)}$$

Where:

L is aerodynamic lift in pounds.
C_L is the lift coefficient.
S_{ref} is a reference area in square feet
ρ (rho) is the density of air in slugs per cubic foot.
V is speed of the air over the vehicle in feet per second.
D is aerodynamic drag in pounds.
C_D is the drag coefficient.

The density of the air (ρ) varies with altitude and temperature. A standard has been established for these variations. For the purpose of the examples in this report as well as the report on vehicle test the air density at sea level on a standard day, 0.002377 slugs per cubic foot, will be used.

4.1 Lift

The aerodynamic lift affects the acceleration performance through the rolling friction term in Newton's second law of motion. Lift also changes the traction of the tires. The lifting force increases as speed increases. When the lift is equal to the weight of the vehicle, there is no load on the tires. There have been several instances of racecars "flying" because of this situation. It is more common to have a situation where the drive will experience a lightening of the force required to steer as speed increases. This is due to the increasing lift. A spoiler is the primary device used to control lift. The spoiler can be designed to generate lift in a downward direction. This type of lift is called down force. This force can be tailored to increase the load on the tires, which improves traction. On the design of modern racecars, the generation of down force is more important than the reduction of aerodynamic drag. A Formula 1 car has a lift coefficient around –3, which results in 1000 pounds of additional "weight" at 100 MPH. For street cars and racecars derived from street cars the contribution of lift on performance is usually small. Typical lift coefficients for these types of vehicles can vary from 0.35 to 0.01. Rewriting equation 4-1 for sea level, standard day and speed in MPH results in the following equation:

$$L = 0.002558 \times C_L \times S_{ref} \times MPH^2 \qquad \text{(equation 4-3)}$$

4.2 Drag

The aerodynamic drag has a greater effect on the acceleration capability of a vehicle. The power loss due to aerodynamic drag increases eight times when the speed doubles. That means that if the power lost to aerodynamic drag at 30 MPH is a paltry 2 HP at 60 MPH the power lost becomes 16 HP and by 120 MPH the power lost becomes a respectable 128 HP.

Estimating the drag coefficient for a vehicle can be accomplished through several methods similar to those used for lift coefficient. Estimating drag can be extremely complicated and difficult. Measuring drag can be done fairly easily with a road test. It is common to break down the drag coefficient into the areas of the vehicle that are generating aerodynamic drag. Areas that require modification to reduce drag can be identified by this method. The following table outlines the estimated contributions to drag for a typical vehicle:

Component	**% of Total C_D**
Body Surface	5%
Rear of Body	15%
Windshield	10%
Underside of Body	15%
Airflow into Cabin	10%
Wheel Openings	10%
Ground Effect	5%
Engine Cooling	15%
Protruding Parts	15%

The drag from the body surface is due to the shape, size and surface finish of the body. The body shape implies a smooth body without and interruptions such as gaps, handles, mirrors or other items that disturb the air flow over the body. These items are included in the protruding parts contribution. The rear of the body contribution is due to the air flow separating from the body. An area of low pressure forms in this separation which causes the large amount of drag. The windshield portion depends largely on the curvature of the windshield. A wrap around windshield has less drag than a plate windshield. The underside of the body does not typically have a smooth surface. This type of underside causes a large amount of drag. The airflow into the cabin and wheel opening contributions are due to openings in the basic body shape. The ground effect is the drag due to the close proximity of the ground. The engine cooling drag is due to taking air inside the car to cool the engine.

Using these contributions, there are several areas to reduce the drag. The specific methods to employ the drag reduction modifications depend on the actual vehicle. Mild modifications can be expected to reduce the drag by 10% without greatly changing the vehicle. These modifications would include eliminating protruding parts, sealing gaps, and simple modifications to the underside. More radical modifications can be made to reduce the drag further; 25-30%.As with the aerodynamic lift, this equation for aerodynamic drag can be rewritten as:

$$D = 0.002558 \times C_D \times S_{ref} \times MPH^2 \qquad \text{(equation 4-4)}$$

Many times the values of C_D from different vehicles are compared to state that one vehicle has less drag than another. This comparison is most often an invalid comparison unless the reference areas of the two vehicles are equal. A value for comparison would be C_D x S_{ref}, which is known as equivalent flat plate area.

5 Measuring Performance

It is possible to measure the performance of a vehicle using the relationships discussed through simple road tests. Electronic devices exist that are used to aid in measuring acceleration. Most of these devices do not measure or account for the horsepower lost to rolling friction or aerodynamic drag. These tests will measure the forces due to rolling friction and aerodynamic drag as well as the horsepower and torque output of the engine. The performance is measured by calculating the change in speed over a period of time which is equal to acceleration (equation 3-6).

These tests should be accomplished on a smooth, flat section of road with little or no traffic. The local traffic laws must be obeyed during these tests. The change in vehicle speed is timed during all of the tests. This timing should accomplished by someone other than the driver. This is for safety reasons.

The performance tests discussed are three variations of an acceleration test. 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 data collected for the test are vehicle weight, speed and time. 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.

Vehicle weight can be determined by few different methods. The simplest method would be to find vehicle weight in manufacturer documentation. However, the source may not reflect the actual weight of the test vehicle. A better method would be to actually weight the test vehicle. This can be accomplished by putting the test vehicle on a scale large enough to weight the vehicle. Such scales can be found at most recycling facilities. Another method would be to use a set of corner scales. These scales are placed under each wheel to measure the weight carried by each wheel. The sum of the values from each scale is the total vehicle weight.

Speed and time are to be recorded during the test. Again, there are a few options as to how this data can be collected. The most obvious would be to collect the data as the test is being conducted. This method could be done in the vehicle with the driver calling off speeds and an assistant recording the speed and time. An alternate method would be to provide the driver with a radio to the assistant outside of the car. Yet another method might be to record the speed with a video camera then time the test from the video. 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, if the vehicle is so equipped. 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. A 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. The test course can be measured, and specific distances marked. During the test the distance markers would be noted and with the time to reach that point, the speed can be determined. This method has the potential for significant errors from many sources. A better method would be to use a hand held GPS device capable of reporting speed. The speed accuracy of many of these devices is excellent.

The instrumentation to measure time can be as simple as a wristwatch wit a second hand. There are many other instruments to measure time that are more accurate. A relatively inexpensive digital stopwatch with the capability to record several points would be sufficiently accurate for these tests. This type of stopwatch should be selected based don the number of time points that can be recorded, more is better.

Three variations of an acceleration test are considered. Speed will be decreasing during the test and one test will have increasing speeds. The decreasing speed tests will measure the restrictive forces acting on the vehicle. The increasing speed test will determine the power output of the engine.

A decreasing speed test is referred to as a coast down tests. This type of test removes the contribution of the engine. This will allow for the calculation of the forces that slow the vehicle. These forces are used to determine the amount of power required to propel the vehicle forward. The results from these tests are used as inputs for the acceleration test. The coast down test begins a speed slightly higher than the initial speed for the test. The engine is disengaged, typically by placing the transmission in neutral. The time is measured when the vehicle reaches the initial speed. Subsequent speeds are recorded with the time since the initial speed. These data should be collected as often as is practical. Most likely this will depend on the ability of reading the instrument measuring speed. The coast down test does not have to continue until the vehicle comes to a stop. The differences between the two types of coast down tests are determined by the starting speed of the test. The first coast down test is to measure the rolling friction and the second test is to measure aerodynamic drag.

The first coast down test is started at low speed. The low speed will minimize the contribution of aerodynamic drag to the deceleration of the vehicle. Typically shaped vehicles have low aerodynamic drag at speeds below 40 MPH. This test should also be concluded at a very slow speed. This enables the collection of the greatest quantity of data. The low speeds of this test also minimize the contribution of aerodynamic lift. The data from this test will be used to calculate the coefficient of rolling friction for the test vehicle. As stated earlier, the coefficient of rolling friction is dependant on several factors. The tires and tire pressures at the time of the test should be noted. These items can be changed to determine their affect on the rolling friction.

The second test is conducted at higher speeds to determine the drag coefficient of the test vehicle. This test should end at a speed below the starting 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 configuration of the test that determined the coefficient of rolling friction. For example, the same tires and tire pressures that were used in the low speed coast down test. The higher speeds of this test increase the contribution due to aerodynamic lift. This contribution is part of the force due to rolling friction. Since there is no easy method to measure the aerodynamic lift a value for the lift coefficient can be estimated. Typically shaped vehicles have an approximate value of lift coefficient 0.3. If the lift coefficient is omitted, the lift contribution to rolling friction will be included in the drag force. A reference area is required for data reduction of this test. This area is usually the maximum cross sectional area of the test vehicle. The accuracy of this value is not essential. The only requirement is that value used must be used in subsequent calculations involving the aerodynamic coefficients from this test.

The final test discussed in this report is a maximum acceleration test. The data from this test will allow for the calculation of the engine power. This test does not have to start from a standing start. Similarly, the final speed of this test does not have to the maximum speed of the vehicle. The use of maximum throttle is critical to this test. If less throttle is used, the power calculated from the test results will not be the maximum power available. Variations in throttle during the test will also decrease the accuracy of the test. The data reduction for this test requires the values determined by the two coast down tests. Additionally, the gearing and tire size are also required for this test.

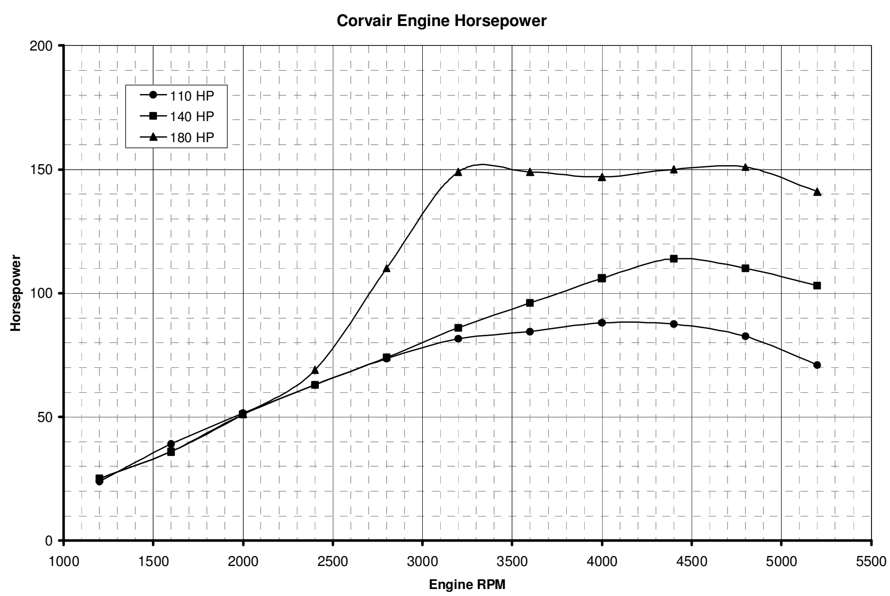
Details on the test procedures and data reduction are included in the testing report. The data reduction process has been automated in a series of Microsoft Excel spread sheets are also included with this report.

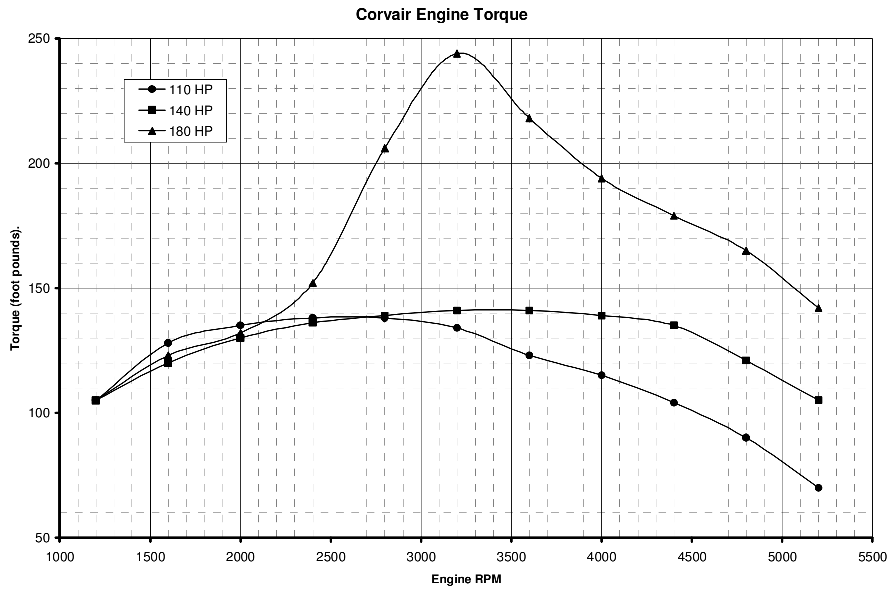
6 Applying the Science

This section of the report will present how the science of vehicle performance is utilized. This will be accomplished with the Chevrolet Corvair as the vehicle. Chevrolet built the Corvair from 1960 through 1969. There were several engine selections and body styles. Our example will be based on a 1966 2-door coupe. Several engine, transmissions and differentials will be presented in the examples to point out the effect these items have on performance.

6.1 Engine Power

The engines considered for the example 1966 Corvair will include three engines. All three are air cooled, horizontally opposed six cylinder engines with 164 cubic inch displacements. The differences in the engines are due to the cylinder head design and the carburetion. The base engine has two single barrel carburetors and an advertised horsepower of 110 HP. The second engine has four single barrel carburetors. Two carburetors open directly with the throttle while the other two begin to open when the throttle is about 60% open. All four carburetors reach full open at the same time. This engine is rated at 140 HP. The final engine has a single carburetor and is turbocharged. This engine is rated at 180 HP. The following charts present the horsepower and torque at the flywheel for each of these engines as installed in the vehicle:





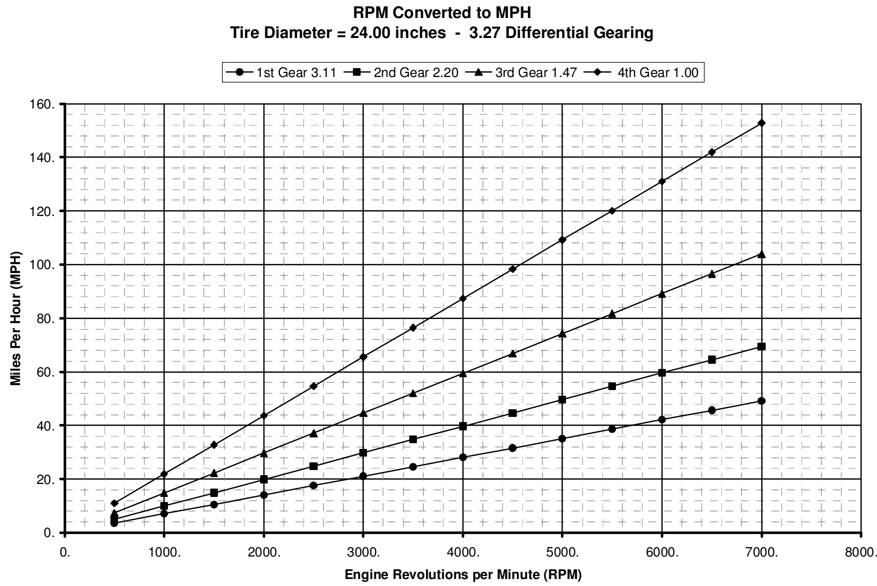
The maximum RPM for all three of these engines was set at 5200. As seen in the previous chart, the advertised horsepower claims were very optimistic. This was a somewhat common occurrence at that time. In the examples, the engines will be referred to by the advertised horsepower ratings.

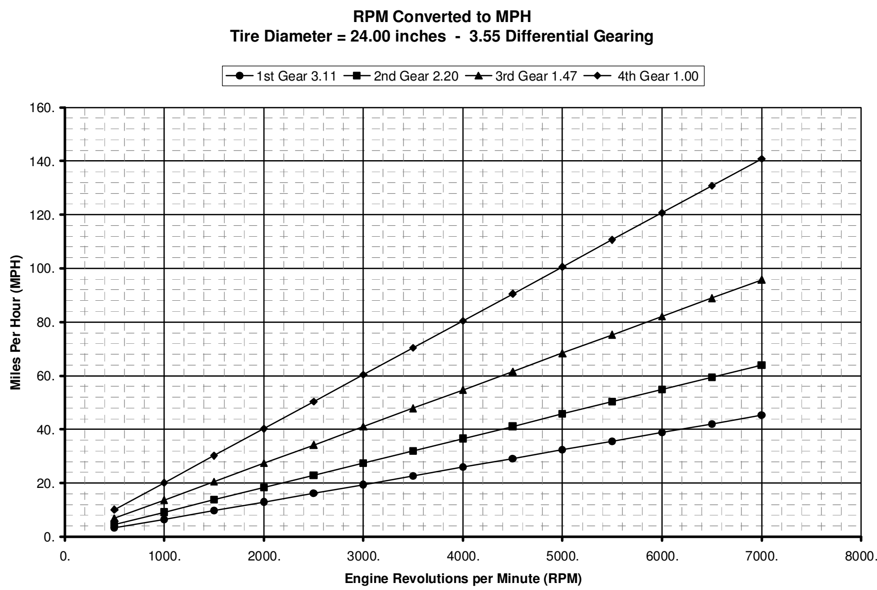
6.2 Differential and Transmission

Two different differentials and two manual transmissions were available for the Corvair in 1966. The differentials have different gear ratios, 3.55 and 3.27. The transmissions are a three speed and a four speed. The following table shows the gearing for each transmission:

Gear	First	Second	Third	Forth
3 Speed	3.11	1.84	1.00	--
4 Speed	3.11	2.20	1.47	1.00

Since the gearing differences between the transmissions are small, only the four speed will be used in the examples. The stock Corvair tire has an outside diameter of approximately 24 inches. The following charts present the relationship between engine RPM and MPH for the combinations of the two differentials and the four speed transmission.





6.3 Drag Estimation

A sophisticated computer program was used model the Corvair body was used to determine the aerodynamic drag coefficient. This program is normally used by the aircraft industry as a virtual wind tunnel. With modification to the computer model, the program is capable of breaking the drag coefficient into different sources. The contribution to drag from the protruding parts was partially calculated with the computer model and partially calculated from a different method the individual parts. The other method involves comparison of the part geometry to a database of known parts. This method accounted for nearly 80% of the drag contribution from protruding parts. The total drag coefficient calculated here is expected to be within 10% of the actual drag coefficient.

The following table lists the component drag coefficients that were calculated:

Component	**ΔC_D**	**Actual % of Total C_D**	**Predicted % of Total C_D**
Body Surface	0.014	3.89%	5%
Rear of Body	0.058	16.11%	15%
Windshield	0.036	10.00%	10%
Underside of Body	0.072	20.00%	15%
Airflow into Cabin	0.022	6.11%	10%
Wheel Openings	0.057	15.83%	10%
Ground Effect	0.014	3.89%	5%
Engine Cooling	0.029	8.06%	15%
Protruding Parts	0.058	16.11%	15%
Total	0.360	100%	100%

6.4 Test Results

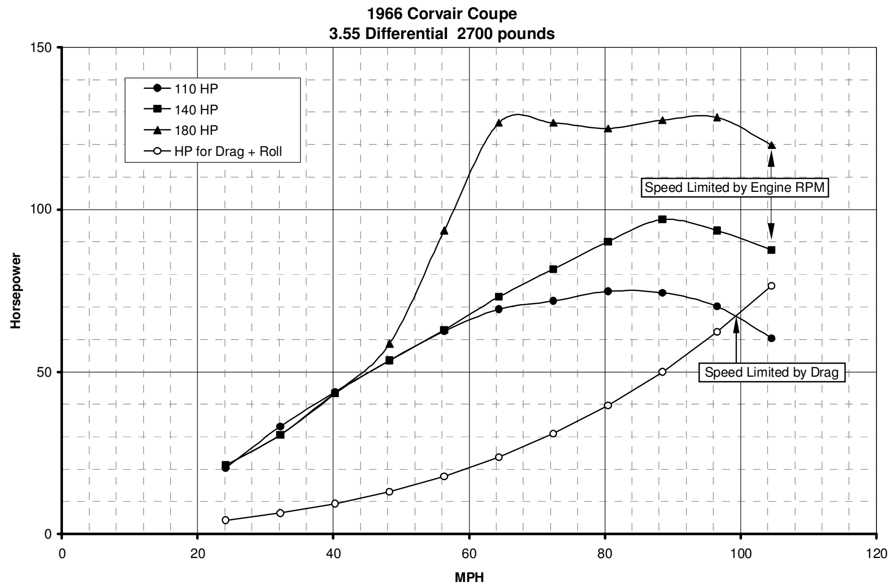
The test vehicle was found to weigh 2700 pounds in the test configuration. The lift coefficient for this vehicle was found to be 0.3 from published GM data. Two low speed coast down tests were conducted to determine the coefficient of rolling friction to be 0.0203. Two high speed coast down tests were accomplished to measure the aerodynamic drag coefficient. The drag coefficient was found to be 0.3623. The test data can be found in the test data reduction spread sheets that accompany this report.

The characteristics of the example vehicle have been established. These characteristics are now used to evaluate the vehicles performance for several different problems.

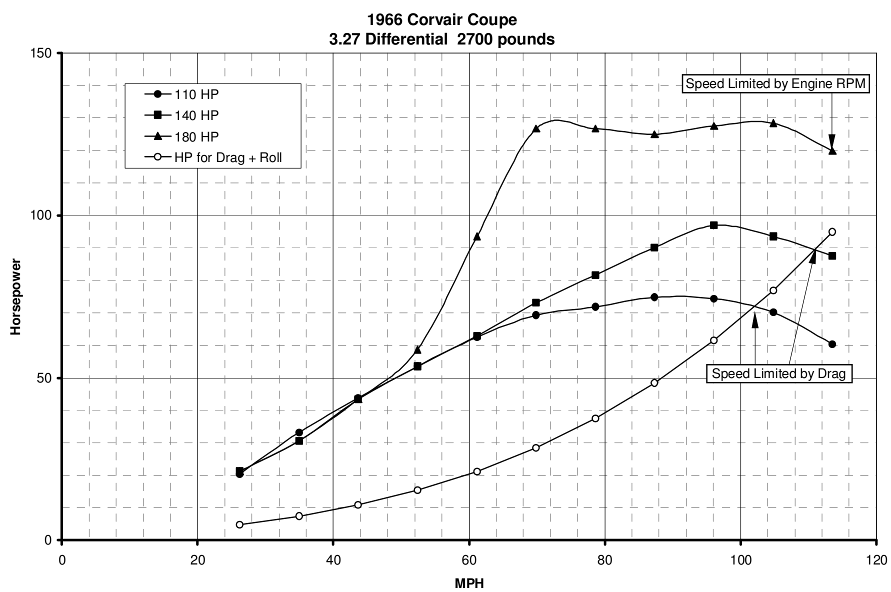
6.5 Maximum Speed

The first example will determine the maximum speed for our 1966 Corvair coupe. For this problem each engine and differential will be used. The power required to overcome the rolling friction and aerodynamic drag and the engine power available at the rear wheels are plotted against speed. This is accomplished by using the conversion of RPM to MPH for the highest transmission gear.

The following charts present this data:



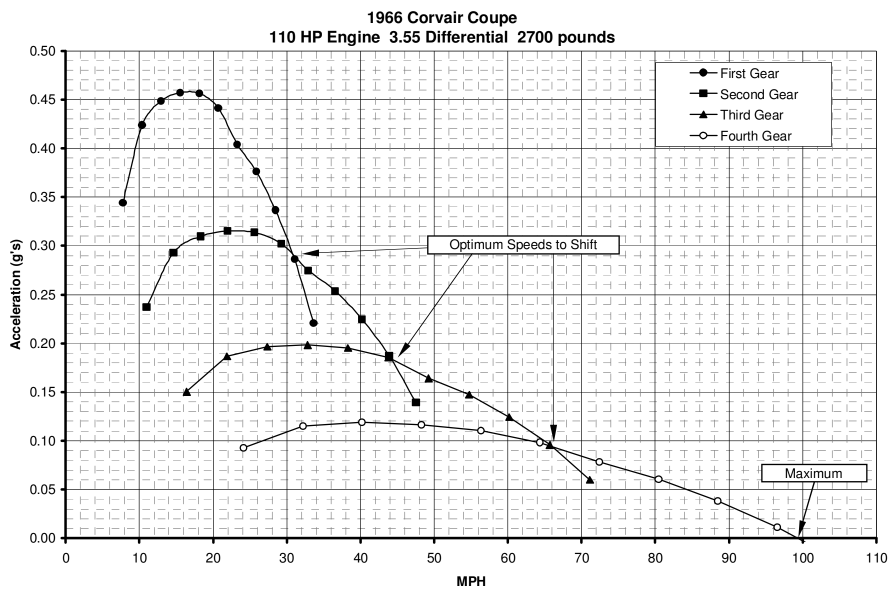
Notice that the power required curve crosses the power available curve for the 110 HP engine. The point where these lines cross is the maximum speed which is drag limited. The vehicles with the other engines have a maximum speed that is limited by the maximum engine RPM. If the differential gear is changed to the 3.27, the maximum speed plot changes to the following:

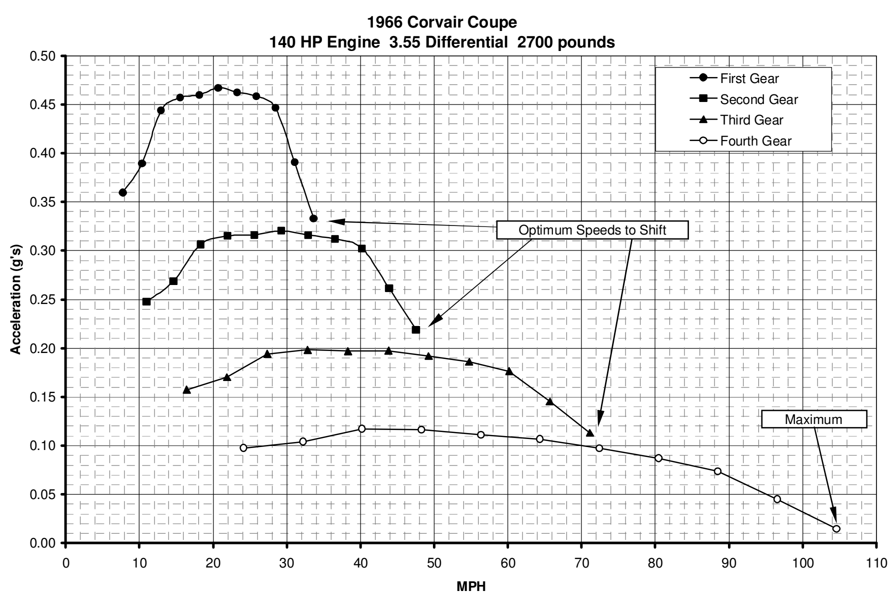


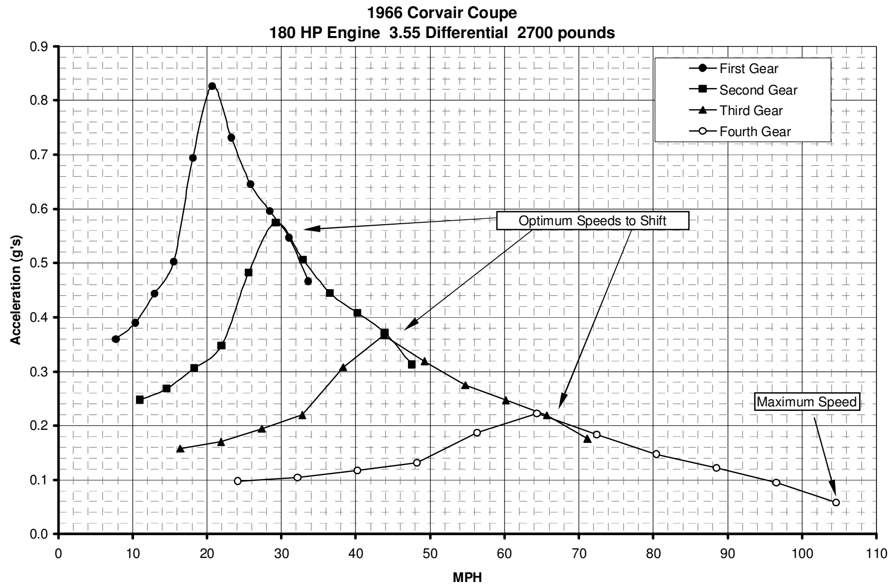
This plot shows, that while the differential change allows the engine to have the capability to reach a higher speed, the 140 HP powered vehicle is now also limited by aerodynamic drag.

6.6 Acceleration and Shift Speeds

To find the maximum speed of the vehicle, the power available from the engine and the power required for aerodynamic drag and rolling friction were calculated for the transmission top gear. The difference between these two lines is the power available for acceleration. The acceleration can be calculated for all gears and plotted versus speed. The following plots show the resulting plots for the three Corvair engines:







From these plots, the speed to shift to a higher gear can be determined. Many times the driver will shift to a higher gear when the acceleration feels like it is starting to drop off. Also, the shift should not always be delayed until the maximum RPM is reached. The shift should be made when the acceleration of the next gear is higher than the current gear. This speed is where the curves cross. If the curves do not cross, the shift should be made at the maximum RPM. The 180 HP chart has some interesting aspects that should be pointed out. First, the peak acceleration in first gear 0.826 g's almost double the maximum acceleration of the 140 HP in first gear, 0.467. The second point is that the backside of the curve, speeds above the peak acceleration, is very smooth. This is can be felt by the driver of the car as a smooth acceleration when shifting through the gears.

It should be noted, that modifications to the engine to increase the maximum RPM might not always result in a faster vehicle. If the vehicle has the maximum speed limited by aerodynamic drag, increased RPM will not give a higher speed. Similarly, if the optimum shift speed is below the maximum RPM, extending maximum RPM will not give greater acceleration.