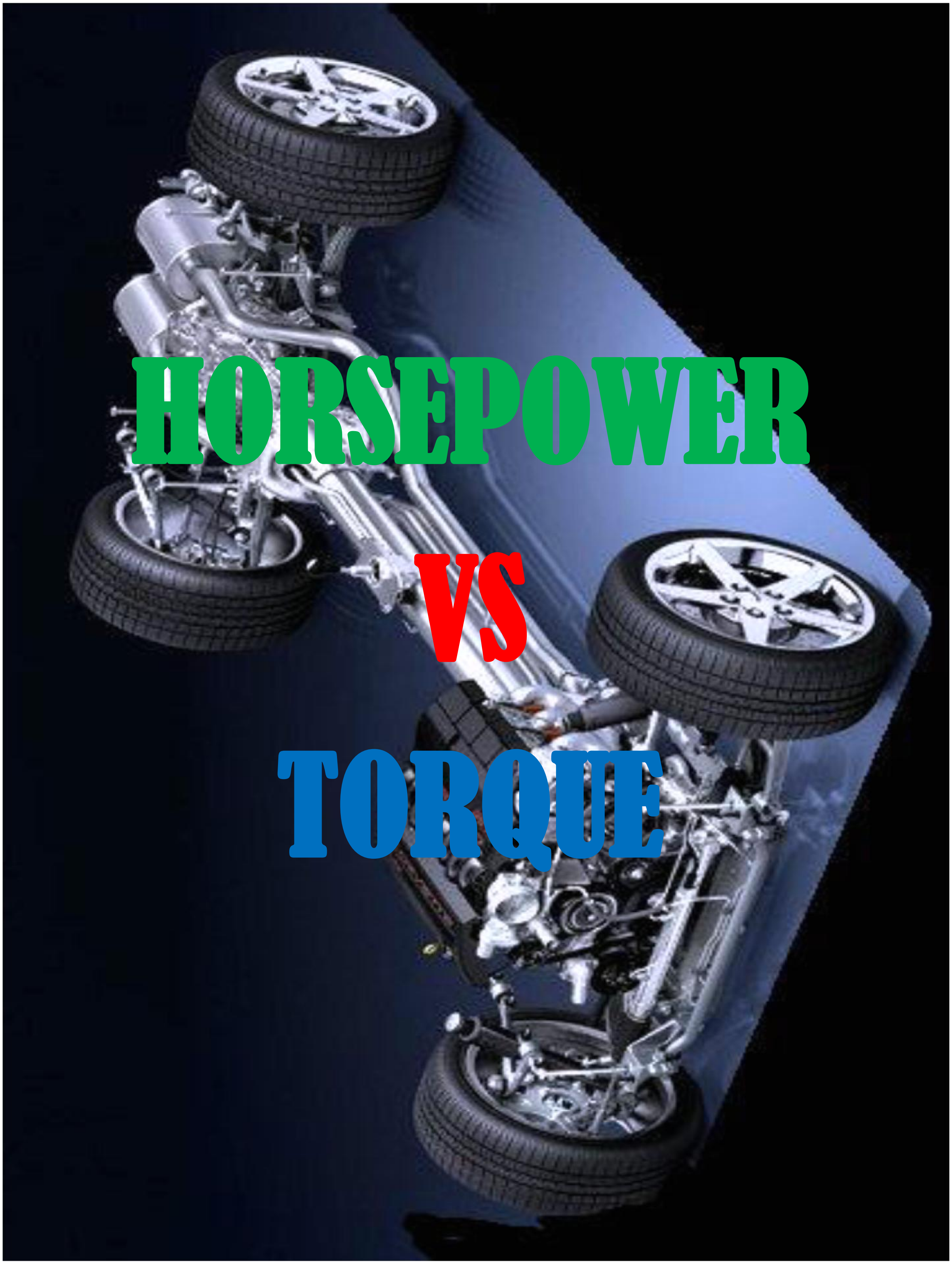
HORSEPOWER VS TORQUE



Introduction

An engine's horsepower and torque values are two things that are often talked about in automotive circles, but may be misunderstood. In this article, I will be looking at how those numbers affect a car's ability to accelerate. Carroll Shelby once said: "Horsepower sells cars, torque wins races." Let's see if that is actually true.

Assumptions

There is no road friction, or friction anywhere for that matter.

1. There are no aerodynamic effects acting on the vehicles.
2. The vehicles are on flat ground.
3. There are no drivetrain losses. The transmission and rear axle are ideal.
4. The vehicles are always moving at some non-zero speed.
5. Gear changes take place instantaneously.
6. The vehicles are at full throttle at all times.
7. There is no turbo lag.

Obviously, none of these assumptions apply to real life, but they will make explanation of many concepts much simpler. Power will be measured in Horsepower. Power and Horsepower will be used interchangeably in this article. Torque will be measured in pound-feet, which will be abbreviated as **lb-ft** or just **tq**.

Torque, Work, Power and Gear

Torque

Torque is a force that tends to cause a rotation. A force applied at a non-zero distance from an object's centre will tend to rotate the object. This is easily seen in real life. If a wrench is placed on a bolt and a force is applied to the end of the wrench, the bolt will turn. If the same pulling force was applied directly to the bolt, it would not turn because the force's direction passes through the object's centre. The amount of torque is determined by multiplying the magnitude of the force by the force's distance from centre.

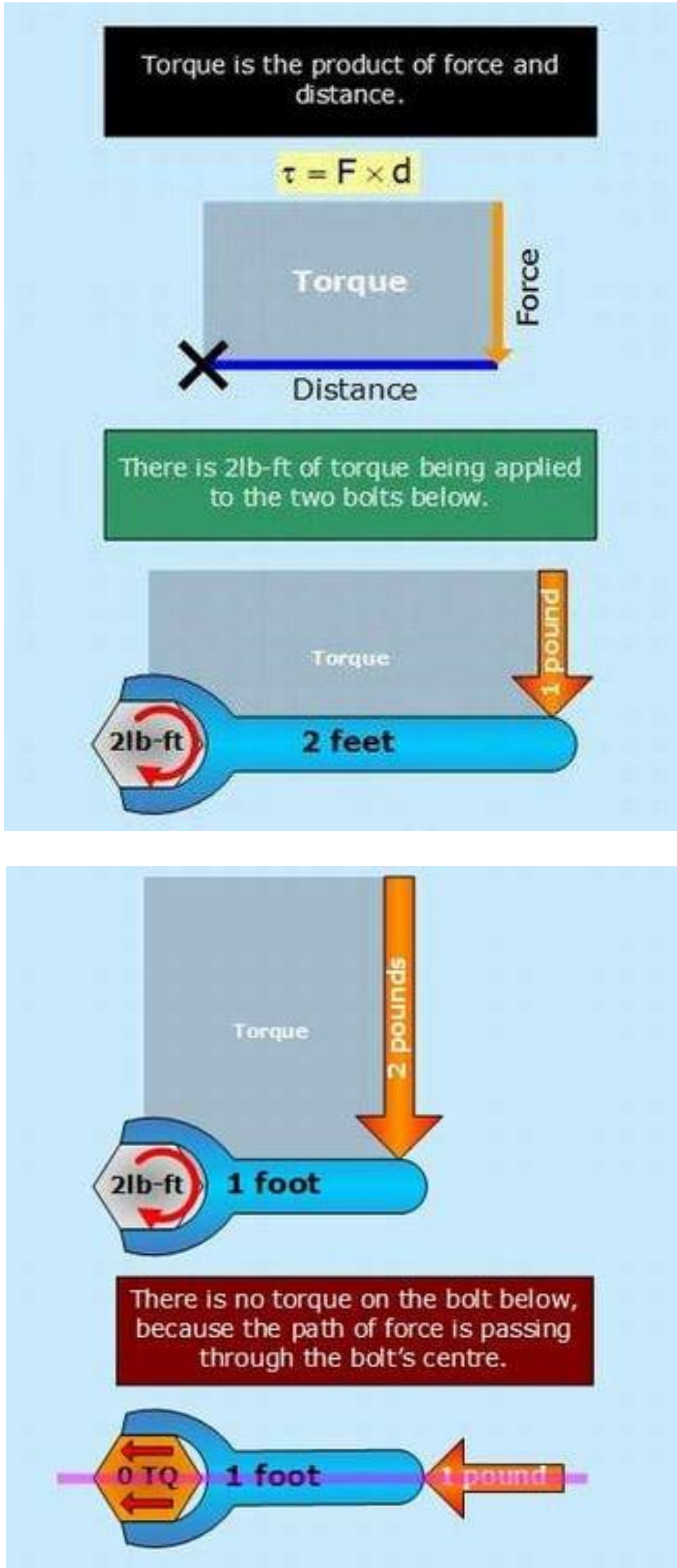
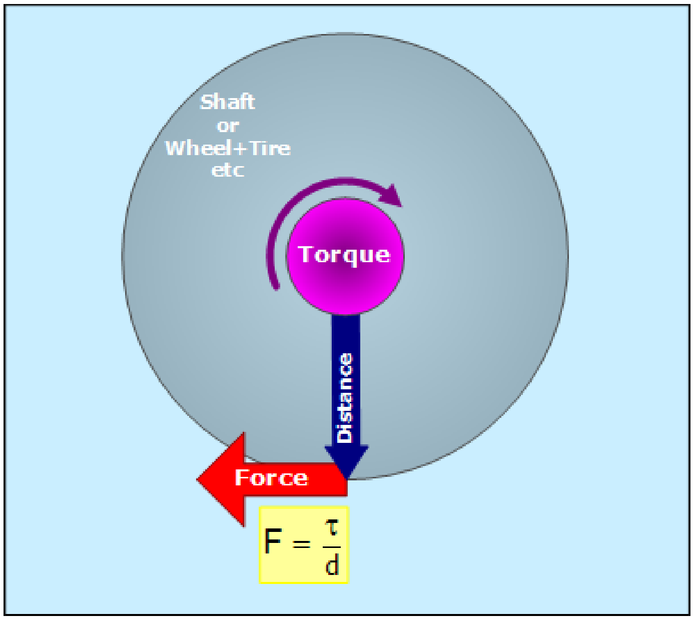


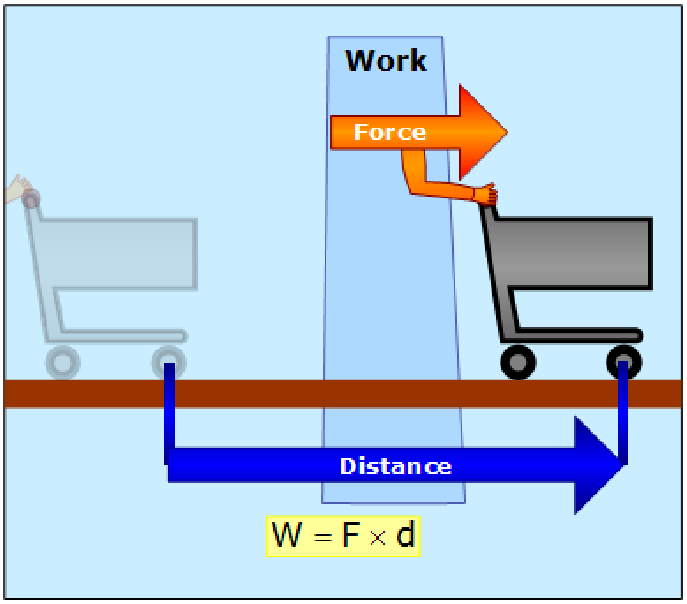
Diagram showing torque.



Torque can be used to create a force at a distance, as seen below.
On a car, this is how the wheel and tire apply force to the pavement.

Work

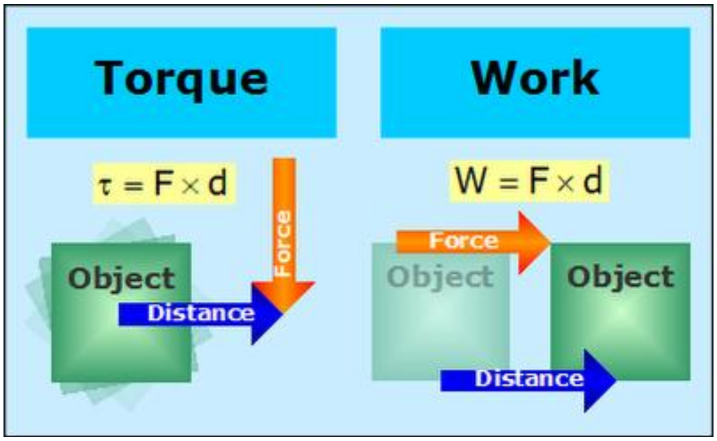
Work is not something that is brought up often when talking about cars. Work is defined as the transfer of energy from one system to another, such as a person pushing a cart. Mathematically, work is the product of force and distance, and has units such as foot-pounds or Newton-metres. The direction of force (or at least a component of it) must match the direction of motion for the force to be considered to have done work. Also, if there is no motion, no work has been done.



Work is done on the object by applying a force along a distance

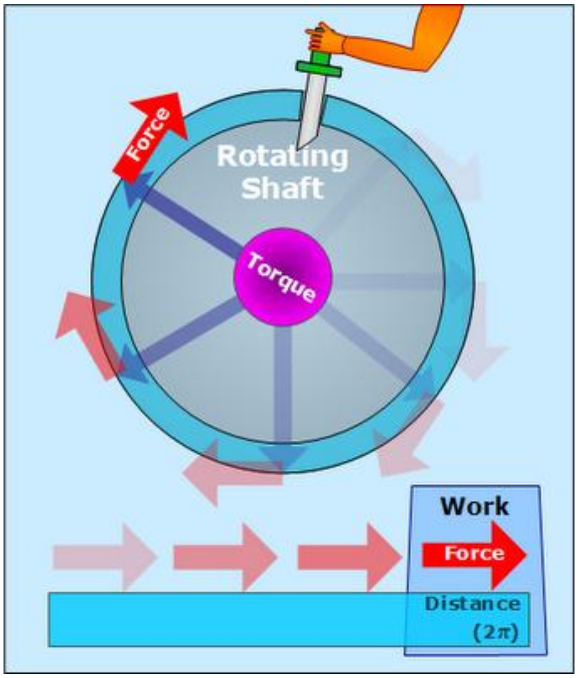
Difference Between Torque and Work

Note that the units for both torque and work are the product of force and distance, yet torque and work are two different things. Torque is a force that tends to cause a rotation, which means that it does not actually cause an object to move along a distance. Work is a measure of energy transfer between systems, which may or may not have been done by a force from torque.



The difference between torque and work

On a rotating shaft, work is done by the force from torque. Torque is a force that tends to cause a rotation, and the shaft is rotating. The force is going round and round, and so is the shaft, so if the shaft was "unrolled", there would be a force traveling along a distance, which is work.



On a rotating shaft, the torque is doing the work

Power

Power is the amount of work that can be done in a certain amount of time, or "the rate of work", or "the rate of energy transfer between systems". The formula for calculating power is shown below:

$$\text{Power} = \frac{\text{Work}}{\text{Time}}$$

$$\text{Work} = \text{Force} \times \text{Distance}$$

$$\therefore$$

$$\text{Power} = \frac{\text{Force} \times \text{Distance}}{\text{Time}}$$

Power is the product of force and distance over a period of time

The above equation can be rewritten in terms of force and speed, as seen below:

$$\text{Power} = \frac{\text{Work}}{\text{Time}} \qquad \text{Work} = \text{Force} \times \text{Distance}$$

$$\text{Speed} = \frac{\text{Distance}}{\text{Time}}$$

$$\text{Power} = \frac{\text{Force} \times \text{Distance}}{\text{Time}}$$

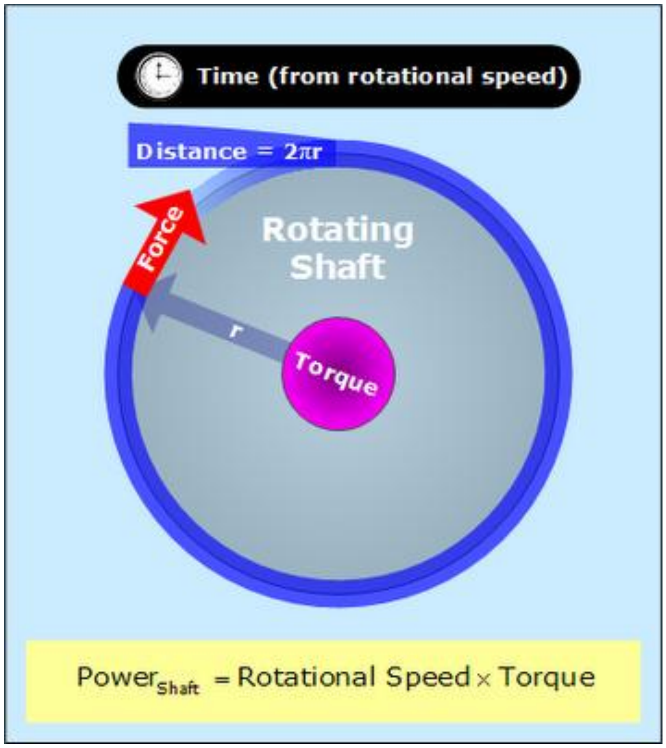
$$\therefore$$

$$\text{Power} = \text{Force} \times \text{Speed}$$

Using the definition of speed, power can be expressed in terms of force and speed

Shaft Power

On a rotating shaft, the force from torque is doing work. The rate of work is dependent upon the shaft's rotational speed. Thus, the amount of power that a rotating shaft has is the product of its rotational speed and its torque. Using arbitrary units, the power formula for a rotating shaft is:



Shaft power using arbitrary units

Units of Shaft Power

When using pound-feet as units of torque, revolutions per minute (RPM) for rotational speed, and horsepower for power, shaft power can be expressed with the following formula:

James Watt made this up.

$$1\text{HP} = \frac{33{,}000\ \text{ft}\cdot\text{lbf}}{\text{min}}$$

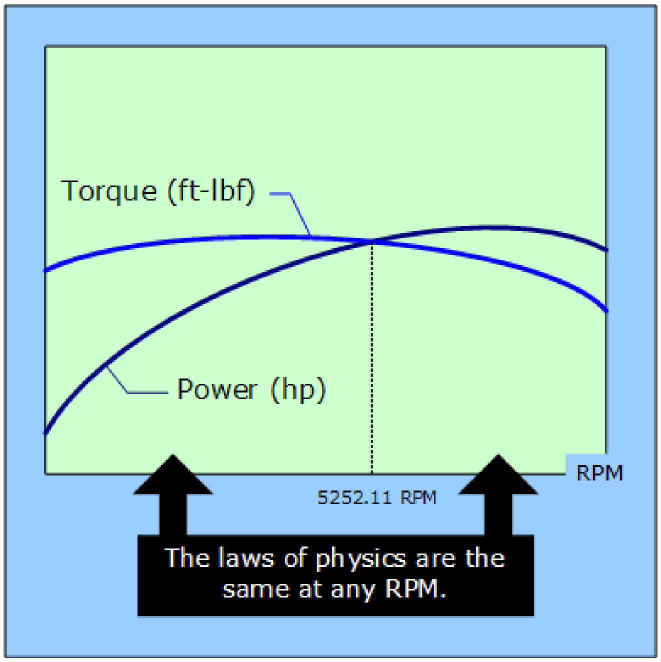
$$P_{Shaft} = \text{Rotational Speed} \times \text{Torque}$$

$$P_{shaft}[\text{HP}] = \frac{\text{TQ}[\text{lb}\cdot\text{ft}] \times \text{REVS}[\text{RPM}]}{33{,}000} \times \frac{2\pi\text{rads}}{1\text{rev}}$$

$$P_{shaft}[\text{HP}] = \frac{\text{TQ}[\text{lb}\cdot\text{ft}] \times \text{REVS}[\text{RPM}]}{5252}$$

Shaft power in horsepower

The above power formula is often misinterpreted as showing that power and torque are the same thing, or that they somehow trade hands with each other at 5252RPM. This mistake is from the fact that a graph of torque in pound-feet and power in horsepower versus engine RPM has crossing lines at 5252RPM. Torque and power play the same role whether an engine is revving below, at, or above 5252RPM. Many diesel engines, and even some gas engines, are not even capable of revving that high at all.



5252RPM is not a significant point in a physical sense. It is merely the RPM at which a graph of torque in pound-feet and power in horsepower would cross when drawn on the same piece of paper. If different units were used, the curves would cross at a different point, yet the principles of operation would remain unchanged.

The above statements can be proven by changing the units for power and torque. Australians often use kilowatts for units of power, and Newton-metres for torque. With that, the shaft power formula becomes:

$$1[W] = 1\left[\frac{N \cdot m}{s}\right]$$

$$1[kW] = 1[W] \bullet \left[\frac{1kW}{1000W}\right] \bullet \left[\frac{1\,min}{60s}\right] \bullet \left[\frac{2\pi rad}{1rev}\right]$$

$$\therefore$$

$$P_{Shaft}[kW] = \frac{TQ[N \cdot m] \times REVS[RPM]}{9549}$$

Shaft power in metric units

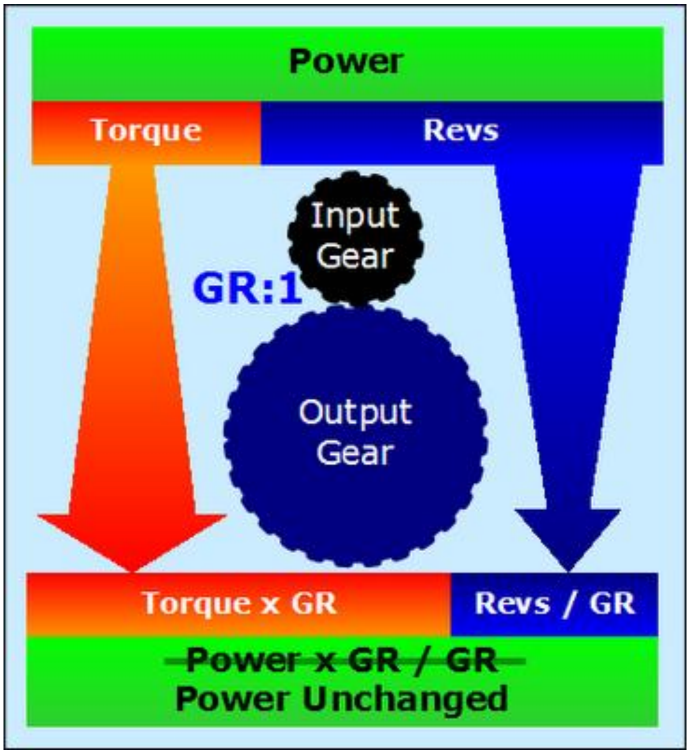
Using metric units, the unit conversion constant is 9549, not 5252 like it was when pound-feet and horsepower were being used. This means that a graph of power and torque versus revs using metric units would have crossing curves at 9549RPM instead of 5252RPM.

Australian engines obey the exact same laws of physics as American engines. The only real distinction between the two is that Aussie engines are designed to run upside down.

Gears

Gears are used to change the torque and rotational speed of a part of a system of rotating shafts, or to change the direction of the transmitted motion. An example of the former would be the car's transmission, while an example of the latter would be the rear axle gears.

An ideal (lossless) gear set transmits an equal amount of power to the output shaft as it received from the input shaft. This means that if a gearbox has a 2:1 gear ratio, the output shaft will be rotating half as fast as the input shaft, but will have double the torque. Below is a drawing that shows the effects of a gear set, using an abitrary ratio, GR.



The gearbox is given a certain amount of power, in the form of torque and revs. It then puts out an equal amount of power, with the revs and torque adjusted according to the gear ratio.

$$\text{Gear Ratio} = \frac{\text{Teeth}_{\text{Output Gear}}}{\text{Teeth}_{\text{Input Gear}}} = \frac{\text{Diameter}_{\text{Output Gear}}}{\text{Diameter}_{\text{Input Gear}}}$$

$$\text{If} \quad \text{Gear Ratio} > 1 \rightarrow \text{Underdrive}$$

$$\text{If} \quad \text{Gear Ratio} < 1 \rightarrow \text{Overdrive}$$

$$\text{RPM}_{\text{Out}} = \frac{\text{RPM}_{\text{IN}}}{\text{Gear Ratio}}$$

$$\text{Torque}_{\text{Out}} = \text{Torque}_{\text{IN}} \times \text{Gear Ratio}$$

Assuming no losses due to friction.

$$\text{Power}_{\text{Out}} = \text{Power}_{\text{In}}$$

Proof:

$$\text{Power}_{\text{Out}} = \text{RPM}_{\text{Out}} \times \text{Torque}_{\text{Out}}$$

$$\text{RPM}_{\text{Out}} = \frac{\text{RPM}_{\text{IN}}}{\text{Gear Ratio}}$$

$$\text{Torque}_{\text{Out}} = \text{Torque}_{\text{IN}} \times \text{Gear Ratio}$$

$$\text{Power}_{\text{Out}} = \left(\frac{\text{RPM}_{\text{IN}}}{\cancel{\text{Gear Ratio}}}\right) \times \left(\text{Torque}_{\text{IN}} \times \cancel{\text{Gear Ratio}}\right)$$

$$\text{Power}_{\text{Out}} = \text{RPM}_{\text{In}} \times \text{Torque}_{\text{In}}$$

$$\text{Power}_{\text{Out}} = \text{Power}_{\text{In}}$$

Formulae used for gears

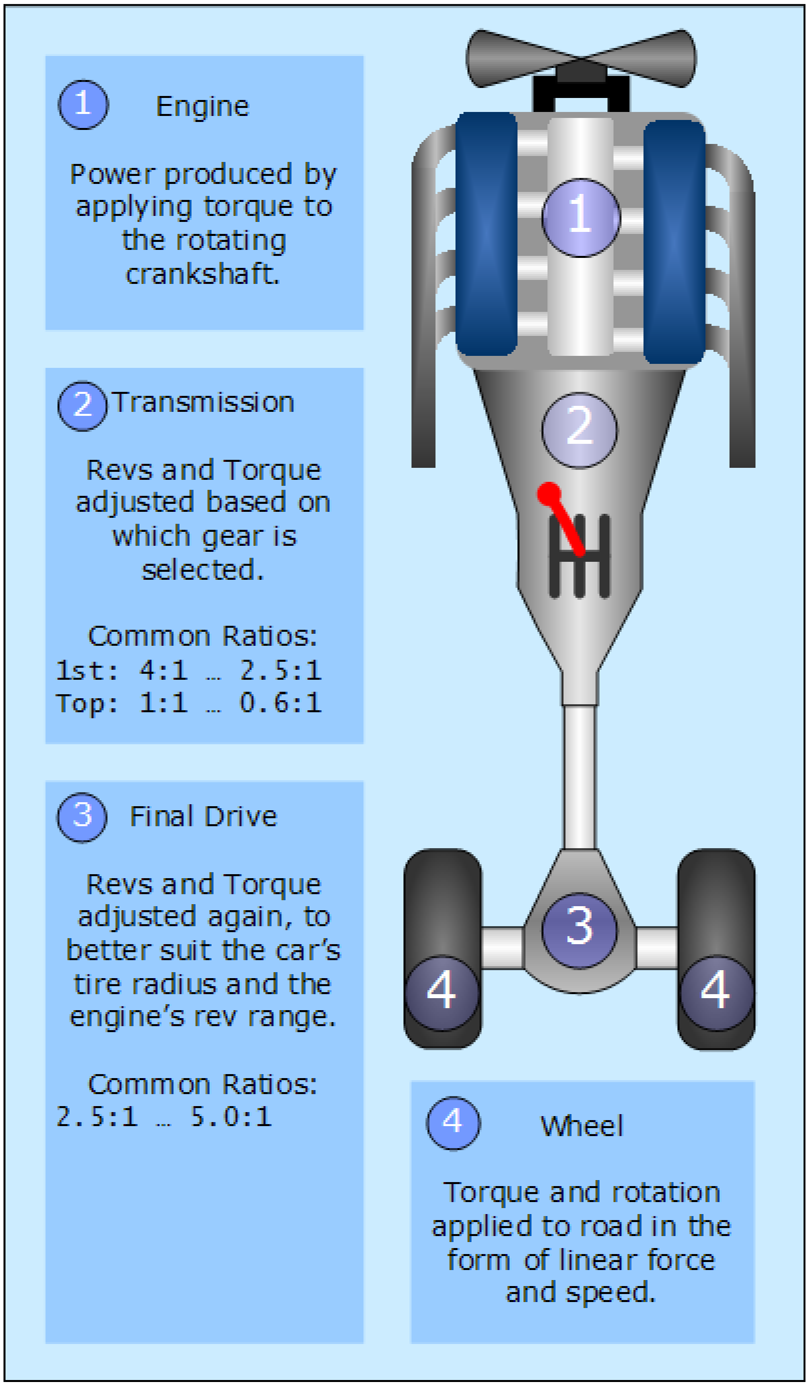
It is interesting to point out that gears and electrical transformers are very similar. Gears change the torque and speed, while transformers change voltage and current. Both gears and transformers put out as much power as they receive. A car battery produces 12 volts and a lot of current, but a spark plug needs up to 50,000 volts and very little current. An ignition coil, which is a transformer, trades away the excess current from the battery to make the high voltage needed for the spark plugs.

Drivetrain Gearing

A car's drivetrain uses multiple sets of gears to control how much of the engine's total power is going to torque, and how much is going to the rotational speed of the wheels.

All gasoline piston engines produce too little torque and too many revs to properly turn the wheels. With 27 inch tires, 6000RPM at the wheels would be 450mph. It also takes a lot more than a few hundred pounds of force to even move something as heavy as a passenger car. This is why all cars have drivetrains which are setup to divide the revs and multiply the torque.

Most cars are fitted with two sets of gearing between the engine and the wheels. The first set is the transmission, which multiplies the torque a certain amount, depending on what gear it is in. Typically, first gear has a ratio near 3:1, while the top gear has a ratio near 0.8:1. After the transmission, there is another set of gears which usually have a ratio of around 2.5:1 through 6.0:1, depending on the vehicle. Below is a diagram of a typical drivetrain found in most cars.



The drivetrain of a car is fitted with a transmission and final drive gearing to adjust the engine's torque and revs to accelerate the car.

$$\text{Force}_{\text{Road}} = \frac{\text{TQ}_{\text{Wheels}}}{\text{Tire Radius}}$$

$$\text{TQ}_{\text{Wheels}} = \text{TQ}_{\text{Engine}} \times \text{Trans Ratio}_{\text{Chosen Gear}} \times \text{Axle Ratio}$$

$$\therefore$$

$$\text{Force}_{\text{Road}} = \frac{\text{TQ}_{\text{Engine}} \times \text{Trans Ratio}_{\text{Chosen Gear}} \times \text{Axle Ratio}}{\text{Tire Radius}}$$

$$\text{Speed}_{\text{Vehicle}} = \text{RPM}_{\text{Wheels}} \times \text{Tire Circumference}$$

$$\text{RPM}_{\text{Wheels}} = \frac{\text{RPM}_{\text{Engine}}}{\text{Trans Ratio}_{\text{Chosen Gear}} \times \text{Axle Ratio}}$$

$$\therefore$$

$$\text{Speed}_{\text{Vehicle}} = \frac{\text{RPM}_{\text{Engine}} \times \text{Tire Radius} \times 2\pi}{\text{Trans Ratio}_{\text{Chosen Gear}} \times \text{Axle Ratio}}$$

$$\text{Power}_{\text{Wheels}} = \text{Power}_{\text{Engine}} - \text{Power}_{\text{Losses}}$$

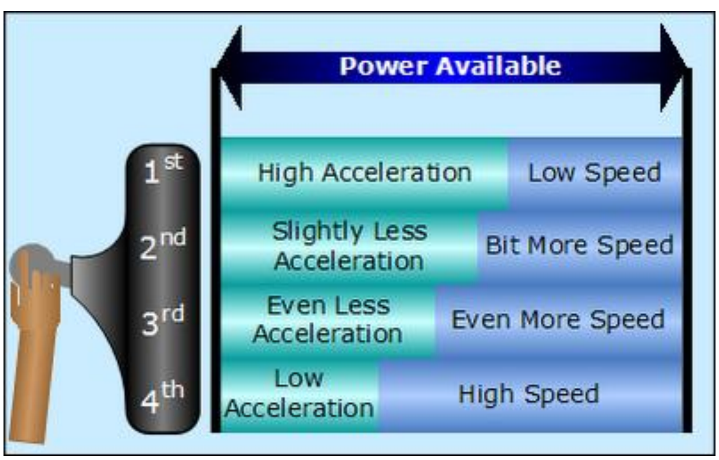
$$\text{Power}_{\text{Losses}} = 0$$ This is an assumption

$$\therefore$$

$$\text{Power}_{\text{Wheels}} = \text{Power}_{\text{Engine}}$$

The wheel torque and revs vary with the engine torque and revs, and the gear ratios in between.

The reason that cars have transmissions with multiple gears is so that the engine can be kept within its operating rev range while the vehicle accelerates from rest to possibly over 200mph. In first gear, there is plenty of acceleration because of the torque multiplication, but very little speed before the engine revs to its redline. In second gear, there is slightly less acceleration, but a slightly higher speed before hitting the redline. This trend of higher speed and lower acceleration continues through each gear in the transmission.



Each transmission gear provides a different amount of acceleration and speed. The combination of speed and acceleration is related to the power from the engine.

Accelerating a Car

Newton's second law of motion states that the acceleration of a body is related to the force being applied and the mass of the body, as seen below:

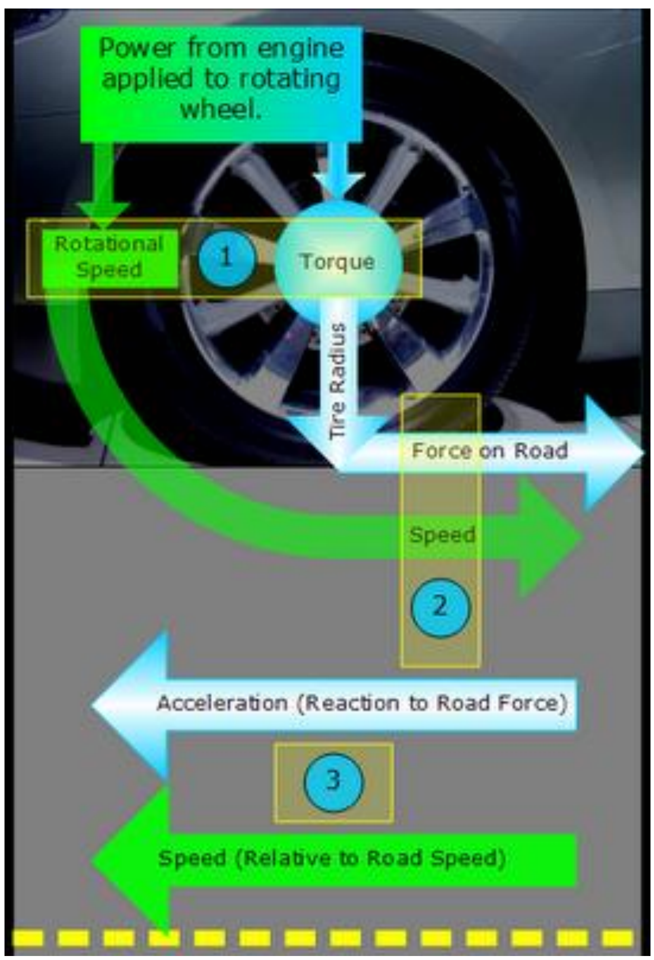
$$\text{Force} = \text{mass} \cdot \text{acceleration}$$

$$\therefore$$

$$\text{acceleration} = \frac{\text{Force}}{\text{mass}}$$

According to Newton's second law of motion, a greater force or a lower mass will result in a greater acceleration.

In order for there to be any acceleration, the force must be applied at the same speed that the object is traveling, for a non-zero length of time. A force being applied at a certain speed for a period of time is power, therefore, the acceleration force on a moving object is determined by the power being applied at that speed.



$$\textcircled{1}\quad Power_{Axle} = Rotational\ Speed \times Torque$$

$$\textcircled{2}\quad Power_{Road\ Surface} = Force \times Speed$$

$$\textcircled{3}\quad Acceleration\ Force = \frac{Power}{Speed}$$

The wheels receive torque and rotational speed from the engine, and lay down a force onto the pavement. It is this force which accelerates the vehicle. The car's speed is directly related to the rotational speed of the wheel.

$$Power = Force \times Speed$$

$$Force = Mass \times Acceleration$$

$$\therefore$$

$$Power = Mass \times Acceleration \times Speed$$

$$\therefore$$

$$Acceleration = \frac{Power}{Mass \times Speed}$$

also:

$$Momentum = Mass \times Speed$$

$$\therefore$$

$$Acceleration = \frac{Power}{Momentum}$$

The acceleration of a moving object is equal to the power divided by the speed and the mass. The product of speed and mass is known as momentum.

The acceleration force that the tire puts to the road comes from the torque at the wheels. This is why the acceleration force is often calculated by passing the engine torque through the drivetrain gearing and wheels, as seen in the formula below. I will refer to this method of calculating the acceleration force as the torque method.

$$Force_{Road} = \frac{TQ_{Engine} \times Trans\ Ratio_{Chosen\ Gear} \times Axle\ Ratio}{Tire\ Radius}$$

The acceleration force can be calculated by passing the engine torque through the entire drivetrain and down the tire radius on to the road.

If the vehicle's speed and the power of its engine is known at a given instant, the force of acceleration can be calculated without knowing anything about the drivetrain gearing, tire diameter, or even the engine torque. I will refer to this method of calculating the acceleration force as the power method. Below is the formula for the power method when using imperial units.

$$1\text{HP} = \frac{33{,}000\ \text{ft}\cdot\text{lbf}}{\text{min}}$$

$$1\text{HP} = \frac{33{,}000\ \text{ft}\cdot\text{lbf}}{\text{min}} \times \left(\frac{1\text{mile}}{5280\text{ft}}\right) \times \left(\frac{60\text{min}}{1\text{hour}}\right)$$

$$1\text{HP} = 375\ \text{lbf} \times \text{mph}$$

$$\text{Power}\,[\text{HP}] = \frac{\text{Force}\,[\text{lbf}] \times \text{Speed}\,[\text{mph}]}{375}$$

$$\text{Force}\,[\text{lbf}] = 375 \times \frac{\text{Power}[\text{HP}]}{\text{Speed}[\text{mph}]}$$

When the power and speed are known, the acceleration force can be calculated directly without knowing anything about the drivetrain.

The torque method and the power method will both produce the same results, as seen in the example below.

Determine the acceleration force on the vehicle below.

Engine HP: 120hp
Engine TQ: 100lb-ft
Trans Gear Ratio: 1.660:1
Axle Ratio: 4.195:1
Tire Radius: 13in (1.083ft)
Speed: 70mph

Torque Method

$$\text{Force}_{\text{Road}} = \frac{\text{TQ}_{\text{Engine}} \times \text{Trans Ratio} \times \text{Axle Ratio}}{\text{Tire Radius}}$$

$$\text{Force}_{\text{Road}} = \frac{100 \times 1.660 \times 4.195}{1.083}$$

$$\text{Force}_{\text{Road}} = 643\text{lbf}$$

Power Method

$$\text{Force}_{\text{Road}} = 375 \times \frac{\text{Power}[\text{HP}]}{\text{Speed}[\text{mph}]}$$

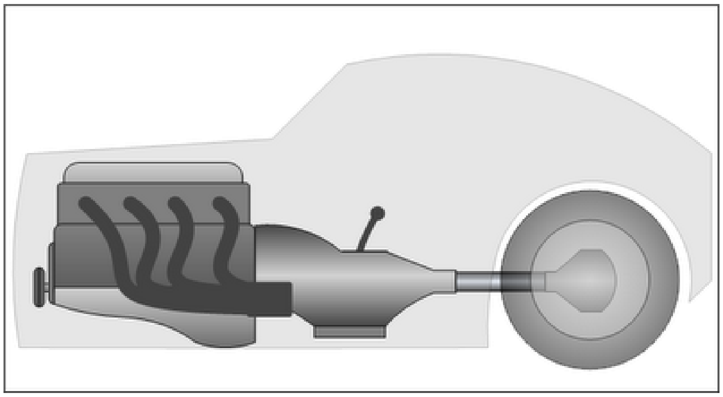
$$\text{Force}_{\text{Road}} = 375 \times \frac{120}{70}$$

$$\text{Force}_{\text{Road}} = 643\text{lbf}$$

The calculated acceleration force is the same when using the torque method or the power method.

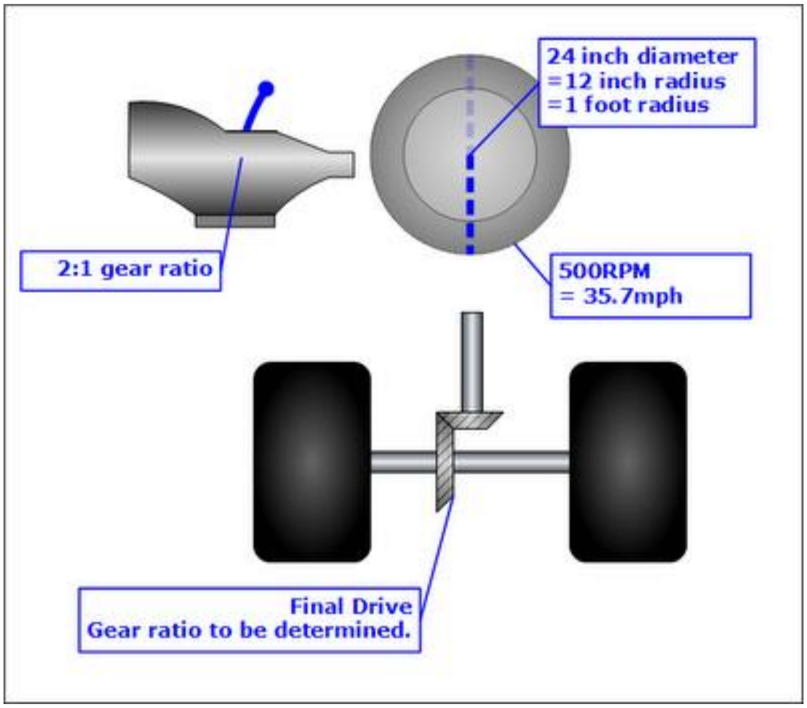
A Simple Example

To demonstrate the effects of power and torque, I will put three different engines into the same car. The car's speed will be the same for each of the three tests, so that the differences in the acceleration force can be seen clearly.



A sample car will be used for the comparison.

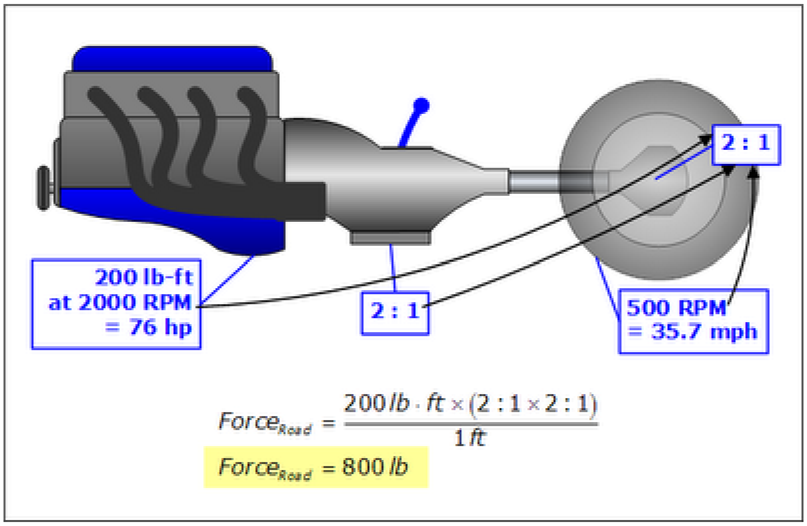
The car has tires with a 24-inch diameter, which gives a radius of 1 foot. The tire will be turning at 500 RPM, which means the car is traveling at 35.7 mph. The transmission will be in a gear which has a gear ratio of 2 : 1. The final drive ratio will be chosen in a way that satisfies the driveshaft RPM and the wheel RPM.



Details of the drivetrain layout.

BLUE ENGINE

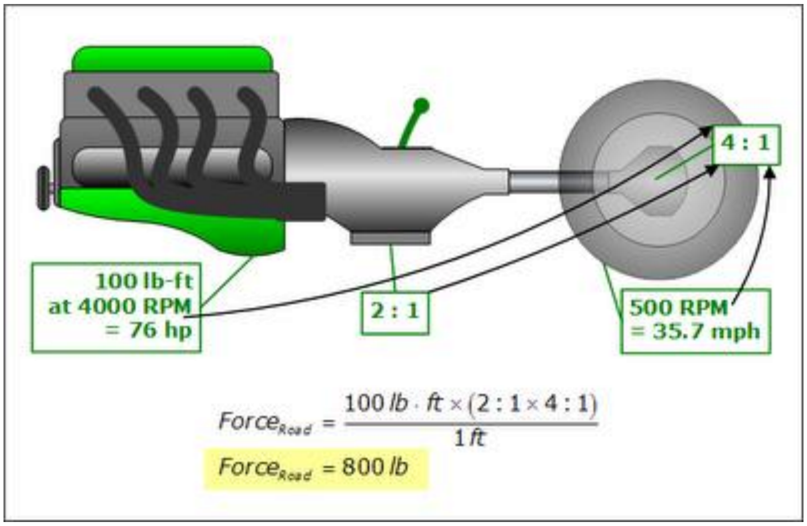
The blue engine is running at 2000 RPM and making 200 lb-ft of torque, which is 76 horsepower. The final drive ratio has to be 2 : 1 to match up with the wheel RPM and the driveshaft RPM. With this setup, the car puts 800 lbf to the road.



The blue engine makes 76 hp, and puts down 800 lbf to the road.

GREEN ENGINE

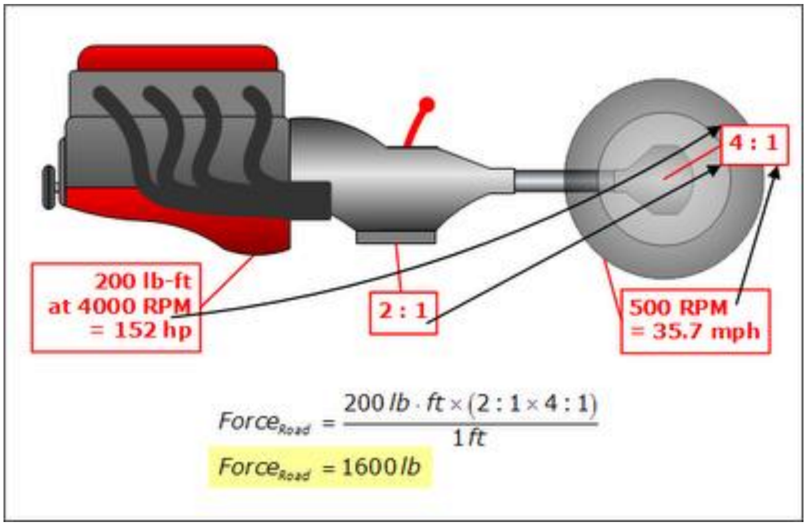
The green engine is running at 4000 RPM and making 100 lb-ft of torque, which is also 76 horsepower. It is revving twice as high as the blue engine, but making only half the torque. The final drive ratio has to be 4 : 1 to match up with the wheel RPM and the driveshaft RPM. With this setup, the car puts 800 lbf to the road, which is the same as the force made by the blue engine.



The green engine makes 76 hp and puts down 800 lbf to the road just like the blue engine.

RED ENGINE

The red engine is running at 4000 RPM and making 200 lb-ft of torque, which is 152 horsepower. It is making just as much torque as the blue engine, and revving just as high as the green engine. The final drive ratio has to be 4 : 1 to match up with the wheel RPM and the driveshaft RPM. With this setup, the car puts 1600 lbf to the road, which is twice the force that the other two engines made.



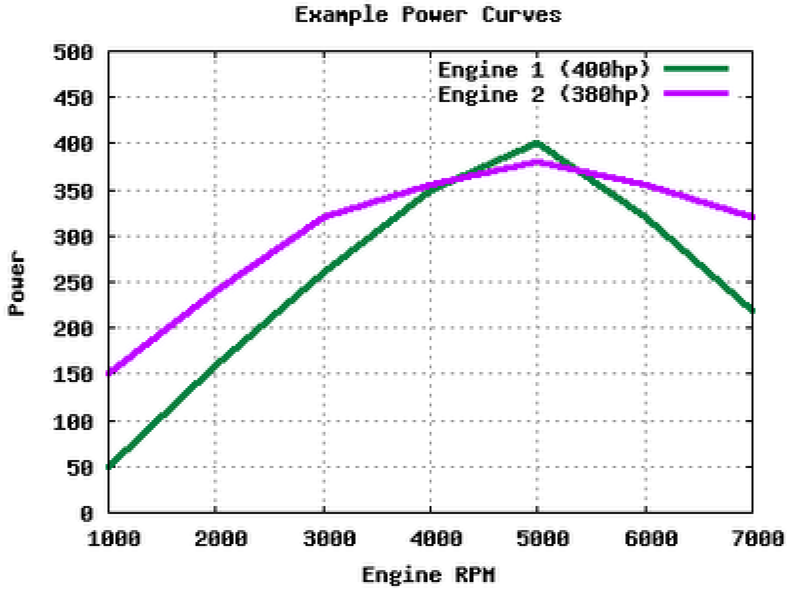
The red engine makes 152 horsepower, which is twice the power of the other two engines.
It is putting a 1600 lb force to the road, which is also twice as high as the other two engines.

It can be seen from the comparison of the above three engines that the most powerful one gave the highest force, and the two which made the same power as each other made the same force as each other as well. The two engines with the same power had a different amount of torque and revs, but the acceleration force was equalized by the final drive gear. This clearly shows that the engine's power, regardless of how much torque it is making or how high it is revving, determines the car's acceleration force.

Power Curves and Power Bands

Engine performance is often described by the peak power figure. A good engine will produce high peak power, and have a very high average power level as well. A graph of power with respect to engine RPM is known as a power curve, and holds important information about an engine's performance across its rev range.

It is possible for one engine to have more average power than another, even with a lower peak power figure, as seen in the example below.



Engine 1 has more peak power than engine 2, but engine 2 has more average power across the rev range. Engine 2 would make for a faster car in most cases.

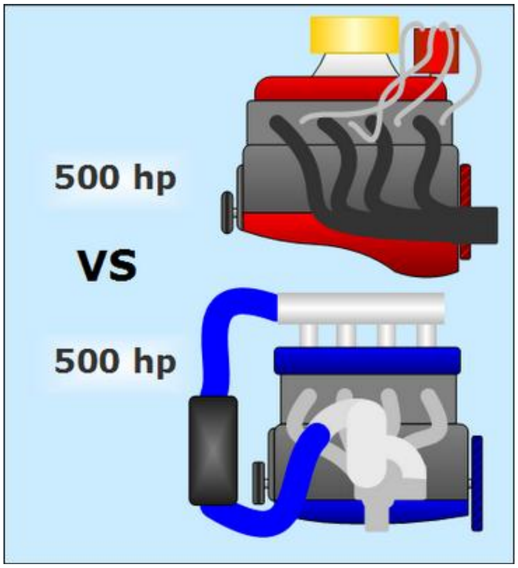
The power band is the rev range where the engine is producing an arbitrary percentage of its peak power figure. For example, the 80% power band of an engine with 500hp would be the rev range where it makes 400hp or more. A wide power band implies high average power.

An engine's power band can be predicted as wide or narrow based on certain characteristics. Some examples are shown in the table below.

Wider Power Band	Narrower Power Band
Large displacement	Small displacement
High Torque	Low Torque
>2 valves/cyl	2 valves/cyl
Variable Valve Timing	No VVT
Supercharged or Turbocharged	Naturally Aspirated
Peak HP, Peak TQ, Redline far from each other in the rev range	Peak HP, Peak TQ, Redline very close to each other in the rev range

Comparing Two Cars

Let's compare two cars with two different engines that have the same peak power output, but different power bands. Both cars have the same curb weight, transmission, tire radius, and so on. In fact, the only difference between the two cars will be the engines. One car will be equipped with a 500hp V8, and the other will have a 500hp turbocharged 4 cylinder engine.



The car with the V8 will be named **Redneck** , and the car with the 4 cylinder will be named **Ricer** . The V8 can rev to 6000RPM and produce a ton of torque, while 4 cylinder can to rev way up to 9000RPM and produce a fair bit of torque. To keep the math very simple, the V8 idles at 600RPM, and the I4 idles at 900RPM. Below are plots of the two fictitious engine's torque and power curves.

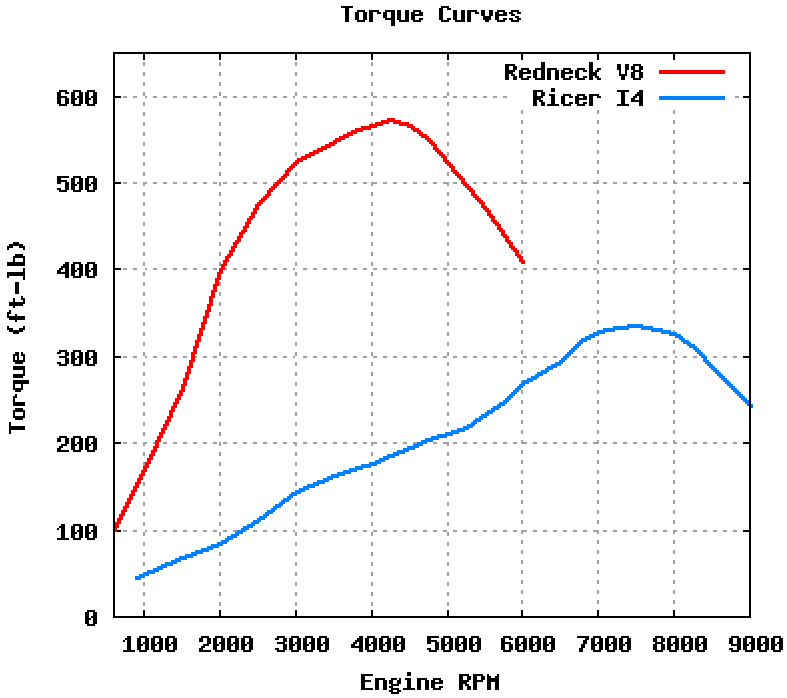


Figure 1: Torque versus RPM for Redneck and Ricer. These are unrealistic curves which have been exaggerated to help illustrate certain concepts.

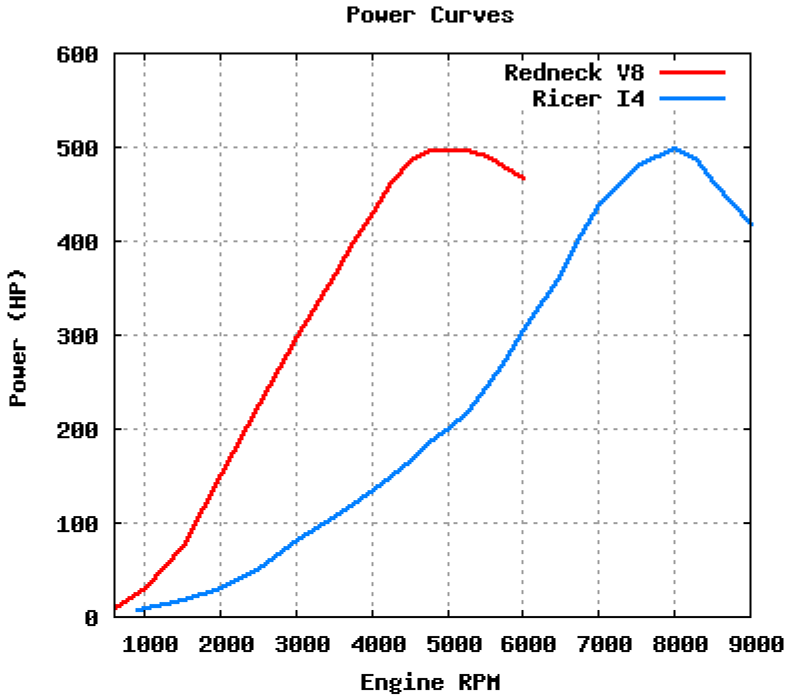


Figure 2: Horsepower versus RPM for Redneck and Ricer. This is calculated from the torque at each RPM.

Both engines produce a peak of 500hp, as specified earlier. The V8 produces 500hp at 5000RPM, and 573tq at 4250RPM, while the I4 produces 500hp at 8000RPM, and 337tq at 7500RPM.

	Ricer	Redneck	Difference
Rev Range	900 - 9000RPM	600 - 6000RPM	50% more for Ricer
Peak Torque	337tq	573tq	70% more for Redneck
Peak Power	500hp	500hp	Equal

Since the V8 was revving low, it needed to produce a lot more torque than the I4 to reach 500hp. At the same time, the I4 needed to rev higher than the V8 to produce 500hp, because it offers up less torque. Below is a comparison of the two engines' power bands.

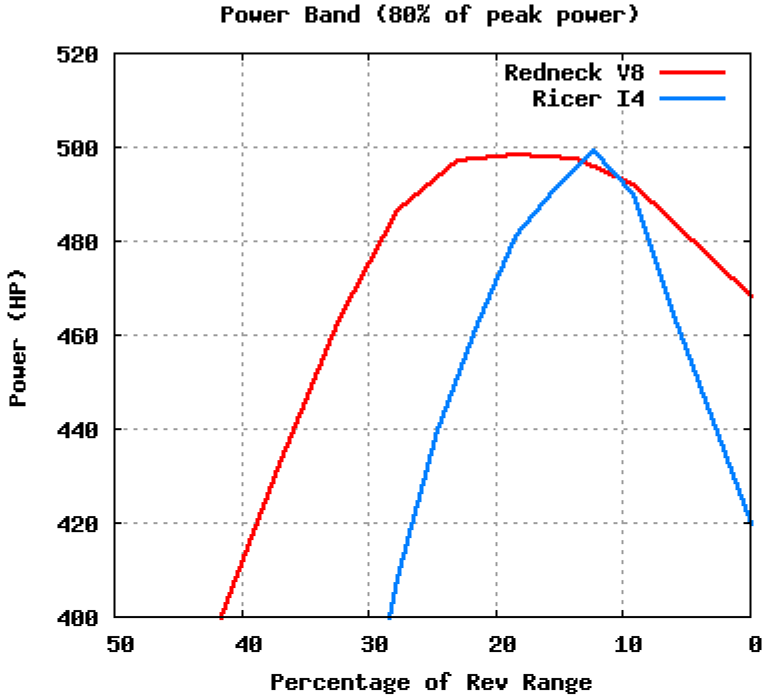


Figure 3: Power band comparison of both engines. Note that the Redneck's average power production (area under the curve) is higher, and that the peak power is the same, at 500hp.

If the x-axis on the above graph seems unusual, there is a separate page on comparing power curves which explains why the rev ranges are not compared directly.

Notice that while both engines have the same peak power figures, the Redneck's engine has a much wider 80% power band. This situation is a considerable advantage for the Redneck. Between the two cars, the one with the made-up V8 is going to be faster than the one with the made-up I4, because the V8 has a higher average power level throughout its rev range.

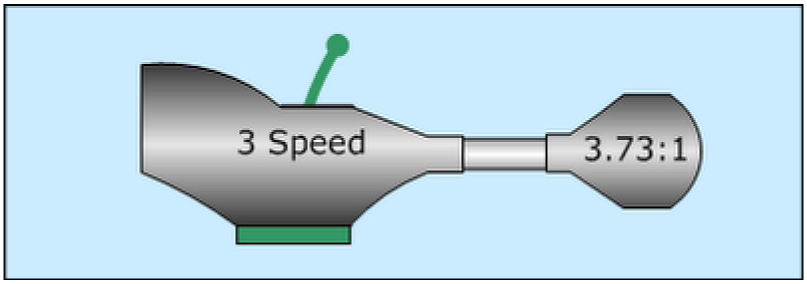
	Ricer		Redneck
Peak Power	500hp	=	500hp
Average Power (Entire Rev Range)	263hp	<	338hp
Average Power (Idle to Redline/2)	106hp	<	166hp
Average Power (Redline/2 to Redline)	385hp	<	460hp
Average Power (80% Power Band)	462hp	<	471hp

An exotic sports car, such as a Lamborghini Murcielago, will have such a wide power band that it can accelerate very hard from almost any engine RPM. This means that it can do things like go from 0-60mph in one gear. This is one of the reasons why exotics have such impressive performance.

Let's now look at how much force the Redneck and Ricer are putting to the road, which as was mentioned earlier, is the force which accelerates the car. For simplicity, both drivers will race by rolling from 20mph, flooring it, and then shifting at their redlines in each gear. Top speed will be considered redline in top gear, because the effects of aerodynamic drag are being ignored.

I'll start off by giving both of them an old TH350 3-speed automatic transmission, and a 3.73:1 final drive (axle) ratio.

Drivetrain Layout
TH350 and 3.73 Axle Gears



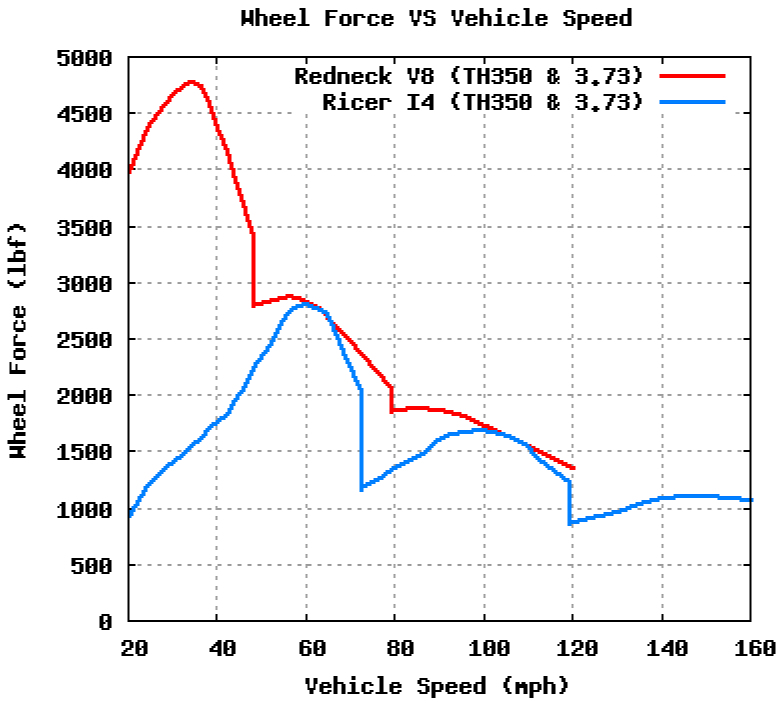
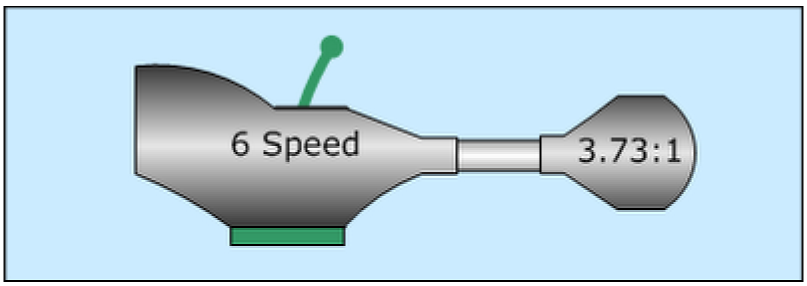


Figure 4: Plot of rear wheel force versus vehicle speed for Redneck and Ricer when using a TH350 transmission and 3.73 axle ratio. The steep vertical drops are the gear changes at redline. Gear changes take place instantaneously for simplification.

Notice that the Redneck has a considerable advantage over the Ricer in first gear, but then not so much in second or third gear. This is because when he shifts into 2nd gear, the transmission doesn't bring him back to idle, but to approximately 3600RPM instead. The Ricer's engine also stays in reasonably high revs after the first gear change, and Figure 2 shows that he has plenty of power at high revs. Also note that the Redneck had to shift into second before the Ricer, so his ability to accelerate between 60-65mph and 100-115mph is about the same as the Ricer's.

Now, let's move into modern day by giving them both a Tremec T56 6-Speed close-ratio manual transmission.

Drivetrain Layout
Tremec T56 6-Speed and 3.73 Axle Gears



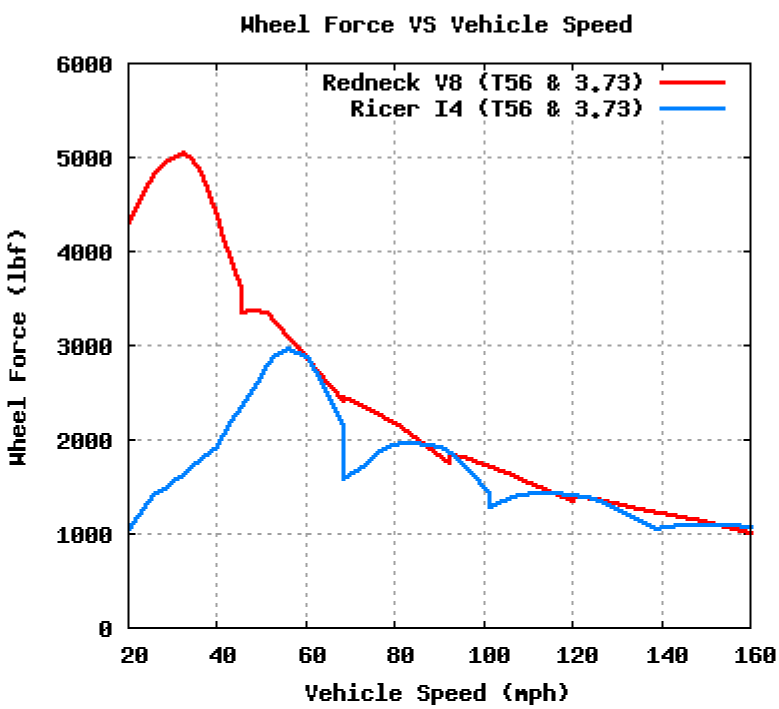
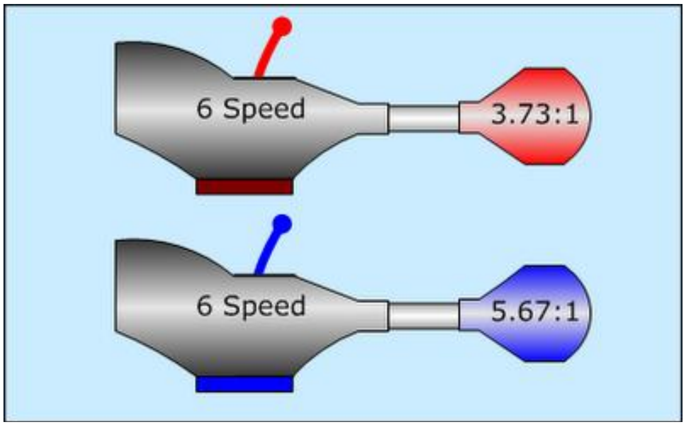


Figure 5: Plot of rear wheel force versus vehicle speed for Redneck and Ricer when using a Tremec T56 transmission and 3.73 axle ratio.
Note that the close ratio transmission has reduced the drops in power at each gear change for both engines, especially for the Redneck.

At certain speeds, the Ricer has caught up slightly. The close-ratio 6-speed transmission helps keep his engine revving near his power peak, and that has helped narrow the gap. The remaining dips in the Ricer's graph after each shift show the effect of having a narrow power band.

The Ricer's acceleration at low speeds is still very poor, but the Ricer has a trick up his sleeve. He is going to install a set of 5.67:1 gears in his axle without the Redneck knowing.

Drivetrain Layout - Tremec T56 6-Speed
3.73 Axle Gears for Redneck
5.67 Axle Gears for Ricer



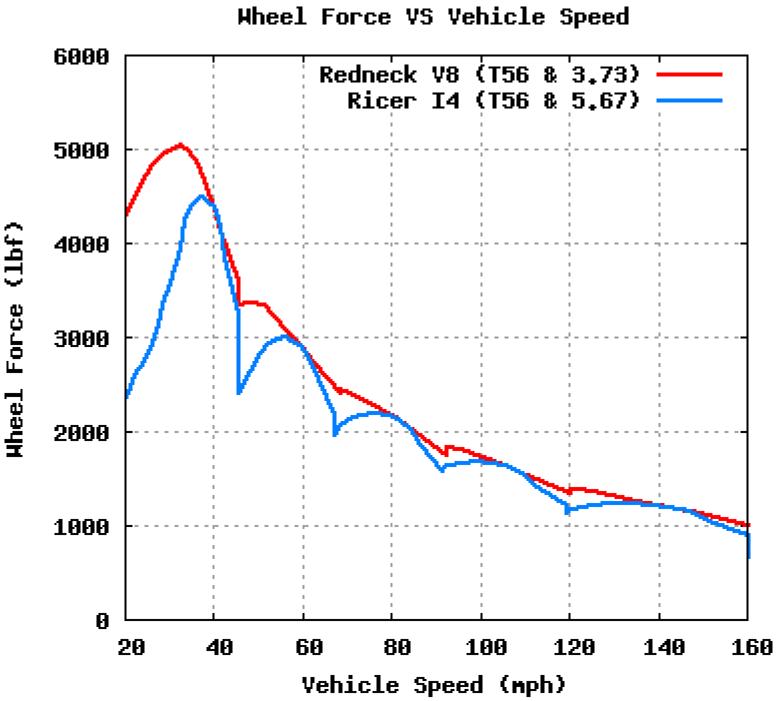


Figure 6: Plot of rear wheel force versus vehicle speed when using a Tremec T56 transmission and 3.73 axle ratio for the Redneck, and 5.67 for the Ricer. Note that both cars shift gears at about the same vehicle speeds as each other now.

The Ricer has pretty much completely caught up now, especially at speeds above 40mph. With those gears he put in, he has traded his higher revs for higher torque to the wheels. Now, for certain vehicle speeds, he can accelerate alongside the Redneck. The Ricer could narrow the gap even further if he changed the transmission gear ratios to better suit his power band. The TH350 and T56 are both intended for use behind large V8 engines.

There are differences in the amount of frictional losses in gear sets with different ratios (and other factors). In the case of a 5.67:1 gear set compared to a 3.73:1 gear set fitted to road cars, the difference would be minor.

The Redneck would also see benefit from putting in different axle gears. However, this "arms race" cannot go on for long, because as the wheel torque is increased, speed is traded away. This means that more gear changes would be necessary to accelerate to a very high speed. Gear changes themselves consume valuable time. An engine with a wide power band may be able to get away with fewer gear changes during a drag race, which can be a considerable advantage.

If both cars were fitted with a Continuously Variable Transmission (CVT) that had an infinite ratio spread which can hold both engines at their horsepower peaks, the acceleration of both cars would be identical.

Low-Speed Acceleration

Even after changing the rear axle gears, the Ricer's car still could not match the Redneck's acceleration from a slow roll up to about 35-40mph. This shows that the benefits of a having a very wide power band are most significant in first gear, and is therefore an important part of tuning an engine for drag racing, where the cars start from rest. Engines which make very little power at low RPM can be made to launch the car quickly from rest by using a high stall torque converter in an automatic transmission, or by slipping the clutch with a manual transmission.

Shift Points

When the Ricer and Redneck were racing, they were shifting gears at their engine's redlines. In many real-life cases, shifting gears earlier may be advantageous for acceleration. An engine with a power curve that begins to "fall off" at very high RPM should be shifted earlier, if doing so would bring the engine to an RPM where it is making more power. Gear shift points should always be chosen in such a way that the engine is putting out the highest average power to the wheels.

Driveability

Driveability is a subjective term used to describe the ability to "access" an engine's power. A naturally-aspirated engine with a wide power band will have very good driveability; putting the pedal to the floor at any speed in any gear should yield reasonable acceleration. On the other hand, a car with a narrow power band would not be considered as "driveable". Passing cars while cruising on the highway often requires dropping a gear to bring the engine's revs up to access the power. This is one of the reasons that luxury cars often come with large, naturally-aspirated or supercharged engines, while small, turbocharged engines are not as common and often found in more "focused" sportscars where outstanding driveability is not expected or required. Engines are sometimes described as being "torquey". This is slang for having good driveability, a wide power band, or a lot of power at low RPM. Streetability is another term which is often used to describe engines with the aforementioned characteristics, along with good road manners, such as a smooth idle and the ability to start in very cold temperatures.

High Torque Engines versus High Revving Engines

The torque that an engine can produce is somewhat related to the displacement of the engine. Larger displacement engines are likely to be much bigger and heavier, making them unsuitable for certain types of vehicles. This is why many small race cars have engines with small displacement, high-revving, and sometimes equipped with forced induction to produce high horsepower. Also, race cars are often given limits on displacement, which means their only chance at producing a lot of power is to rev very high or use boost. A large engine may be able to produce power more reliably than a smaller one, but not necessarily. There are plenty of big, gutless engines that don't last.

Heavy vehicles are almost always equipped with large displacement engines because they require more low-RPM power to accelerate from rest (and very low speeds). As the weight of a vehicle goes up, the acceleration from rest becomes increasingly significant. A 650hp V12 from a Ferrari Enzo could in fact tow a loaded semi at high speeds, but it's unlikely that it would have enough power at very low RPM to get the semi moving in the first place. On the other hand, a huge diesel engine can produce all kinds of power at low RPM to help get the vehicle rolling.

Conclusion

In order to quickly accelerate a vehicle, the engine must be able to make a large force at the speed that the vehicle is traveling. The amount of power determines the force that the engine can create at a given speed, whether it is a very low speed or a very high speed. It does not matter if the engine makes power by revving high or making a lot of torque, because drivetrain gearing can be used to adjust the torque and revs proportionally.

" Peak power sells cars. High average power wins races. "

A vehicle's peak torque and power figures can only give a general idea of performance. The best way to make a good comparison between vehicles is to go racing!