HORSEPOWER & TORQUE

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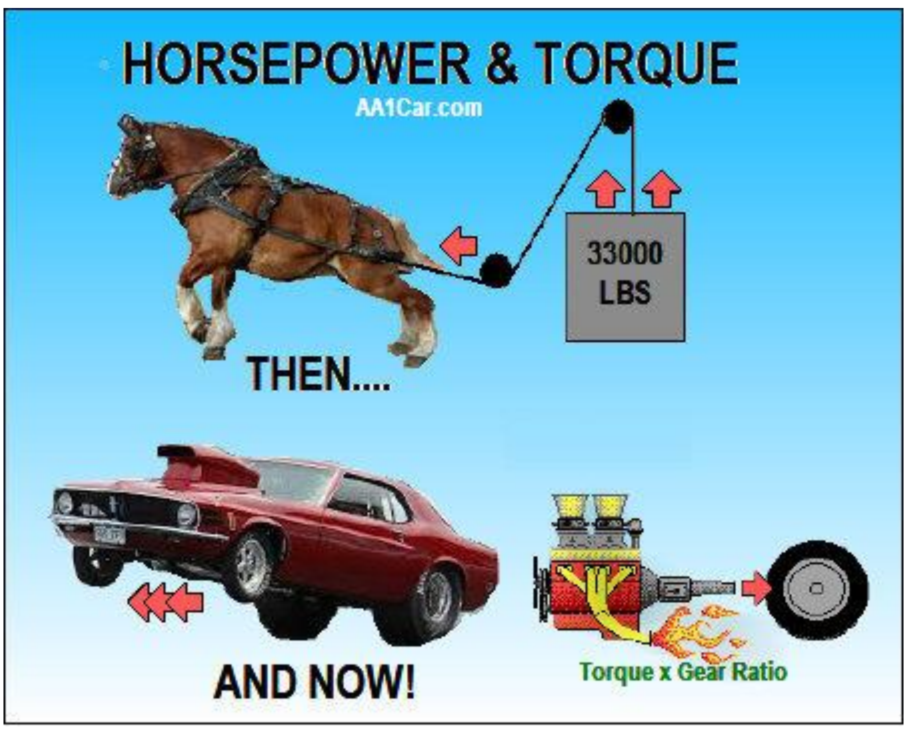
Horsepower and Torque are two quantities that are often used to describe engine performance and to compare one engine or vehicle to another. Many people will gladly pay a premium to get their hands on a high horsepower performance vehicle such as a Corvette ZR1, Dodge Challenger Hellcat, Dodge Demon or Mustang GT500. The sky seems to be the limit these days for high output engines, with some of these vehicles delivering 700 to over 800 hp in stock trim!

What is Horsepower?

Horsepower is a measure of how much work an engine can perform in a given amount of time. It is the application of torque over time to move a vehicle. Horsepower was originally based on how much weight the average draft horse could lift in one minute using a pulley (answer: 33,000 lbs.!). Today, it is a measure of power output equal to 550 ft.lbs. per second, or 745.7 Watts.



There are various ways to measure horsepower, but the most common now used is **NET HORSEPOWER**. This is measured at the engine's crankshaft or flywheel AFTER frictional losses are taken into account. This includes things such as drive belts, water pump, supercharger (if used), turbocharger backpressure (if used), alternator and other accessories (with no load on the accessories other than normal drive friction). How horsepower is measured is spelled out in SAE standard J1349. In days gone by, horsepower numbers were usually inflated by eliminating the normal frictional losses and measuring power with no parasitic on the engine.

NOTE: An engine's net horsepower rating does not take into account frictional losses in the transmission and drivetrain, which can reduce power at the drive wheels by 30 to 40 hp or more. That's why running your vehicle on a chassis dyno and measuring **rear-wheel horsepower** is to most accurate method of determining how much power is actually reaching the road.

Something else you should know is that an engine's net horsepower rating is the peak horsepower it produces, typically around 5,500 to 6,500 RPM or higher. Horsepower output starts out low at idle (maybe only 40 or 50 hp in a typical V8), then gradually increases with engine speed. The higher the engine revs, the more air and fuel it burns, and the more power it makes. Eventually it reaches a point where the power output peaks and begins to drop off because of limitations in airflow (restrictions in the intake system, throttle body, intake manifold, cylinder heads and/or exhaust backpressure).

Horsepower is not measured directly on a dyno. Rather, the dyno measures torque and then calculates a horsepower number based on the engine's torque output.

Horsepower = (Torque x RPM) divided by 5252

Horsepower readings can be converted to Kilowatt readings using this formula:

Killowats = Torque (in N.m) x RPM divided by 9549

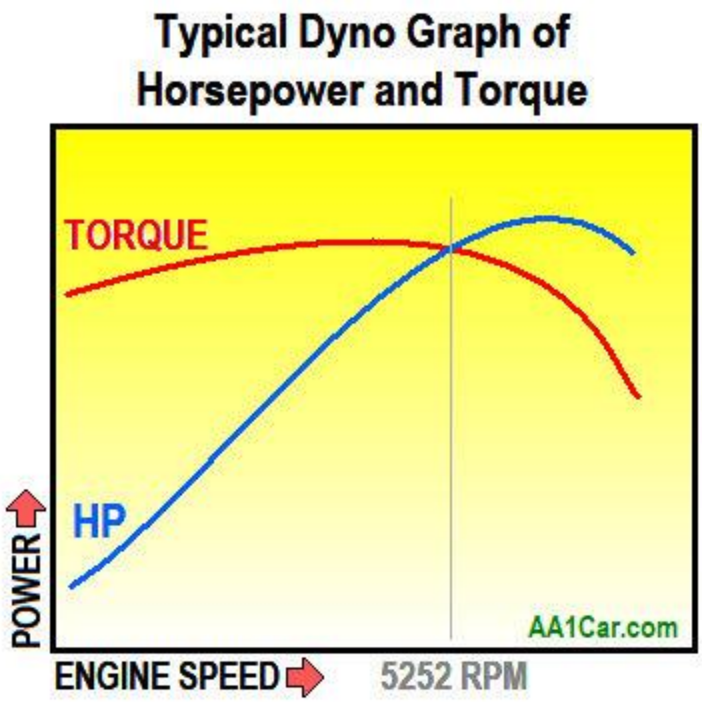
What is Torque?

Torque is the amount of rotational twisting force an engine generates at the crankshaft. Torque is usually expressed in pounds-feet (lb. ft), or Newton Meters (N.m).

Torque = (Horsepower x 5252) divided by Engine RPM

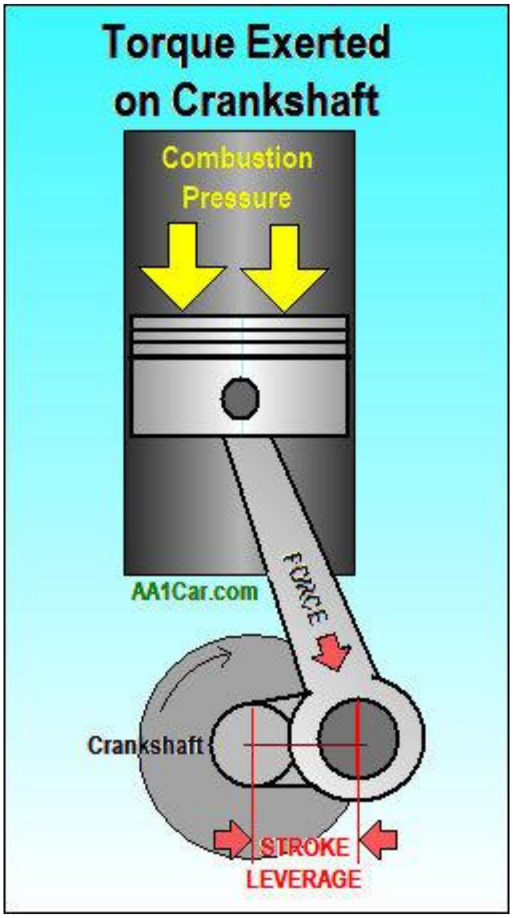
Engine torque is measured on a dyno by applying a calibrated resistance to the power output of the engine (a water brake or an eddy current brake on the dyno). On an engine dyno, the load is connected to the engine's flywheel via a driveshaft. On a chassis dyno, the load is applied to the rollers that are driven by the vehicle's tires.

Torque and horsepower results must then be "corrected" to compensate for differences in local altitude (barometric pressure), temperature and humidity. All of this is spelled out in the SAE J1349 standard for how torque and horsepower should be measured. Such corrections are needed because thinner air at higher altitudes reduces an engine's power output . So does hotter drier air. If the dyno results are not corrected, they can be misleading and result in lower than expected numbers. Likewise, an unscrupulous dyno operator can play with the correction factor to inflate or exaggerate the horsepower and torque numbers.



When you look at an engine dyno graph of torque and horsepower output, the torque line always starts out high and the horsepower line always starts out low. As RPMs increase, torque goes up somewhat but not as fast as horsepower. Horsepower climbs quickly with RPM. When the engine reaches 5252 PRM, the torque and horsepower lines cross. Horsepower usually continues to climb before dropping off while torque continues to drop after 5252 RPM.

At low RPM, torque is gets the vehicle moving and helps it accelerate. At higher RPM, horsepower takes over and keeps then vehicle going. A crankshaft with a longer stroke will create more torque than a crankshaft with a shorter stroke because of the difference in leverage. It’s the same concept as using a long handle wrench to tighten a bolt versus a shorter wrench. You can apply more force with the longer wrench because it has greater leverage.



An engine that produces lot of low to mid-range torque (off-idle to 3,500 RPM) will provide better throttle response, acceleration and drivability on the street than an engine that makes most of its power at higher engine speeds. With a drag car or race car, high numeric gear ratios in both the transmission and differential can maximize the acceleration capabilities of an engine that makes most of its power above 6,000 RPM.

Factors that influence the RPM range where an engine produces peak torque include camshaft timing, duration and valve overlap (less duration and overlap increase low and mid-range torque), also the size (volume)of the intake runners in the cylinder head (high velocity flow is better for torque than huge flow numbers), the length of the intake runners (longer is better for torque), and the size of the throttle body or carburetor (bigger is better for peak horsepower, but too big reduces torque and throttle response).

The most common mistakes that amateurs make when building a performance engine is to over-cam it and to install a carburetor that is too big for the engine. A hot cam with too much valve overlap and duration reduces intake vacuum and kills low and mid-range torque. Always follow the camshaft manufacturer's recommendations for best results. As for carburetor sizing, the carb's Cubic Feet per Minute (CFM) rating should not exceed the displacement of the engine by more than about 10 to 15 percent for drivability, throttle response and good low to mid-range torque. On race engines it doesn't matter because most race engines are built to deliver peak horsepower within a narrow high RPM range.

Torque Multiplication

The cool thing about torque is that you can use gears to multiply the force exerted by the engine to the drive wheels. The higher the numeric ratio of the gearing, the greater the torque multiplication.

Torque output at the wheels = Engine torque x transmission gear ratio x final drive ratio

Vehicles powered by internal combustion engines have transmissions to multiply the amount of torque as the vehicle starts from a dead stop and accelerates. First gear may have a ratio of 2.5 to 1, which means an engine that produces say 200 lb.ft. of torque off idle will now produce 2.5 x 200 or 500 lb. ft. of torque through the transmission to the driveshaft.

The gear ratio in the differential also multiplies engine torque. If the rear drive ratio is 3 to 1, the torque being applied to the rear wheels will be multiplied again by a factor of 3 (3 x 500 = 1500 lb.ft.). This is why drag cars have high numeric final drive rations in the differential (4 or 5 to 1 for maximum acceleration down a quarter mile). High gear ratios, however, also makes the engine rev higher as it runs through the gears. This is not so good for fuel economy in a normal street driven vehicle, so the final drive ratios for most cars is 3 to 1 or less to reduce engine speed in top gear for better fuel economy.

What Horsepower and Torque Numbers Actually Do

More horsepower and torque means faster acceleration. That's the bottom line. How fast a vehicle accelerates from 0 to 60 mph, 0 to 100 mph or runs a quarter mile depends on three things: power, weight and traction. Lots of horsepower (or torque), reduced body weight and good traction are what it takes to deliver neck-snapping acceleration.

Many of these high horsepower car cars can hit 60 mph in under 4 seconds. A Dodge Hellcat (707 hp) can hit 60 mph in 3.6 seconds and run the quarter mile in just under 11 seconds. The Dodge Demon (840 hp on race gas) is even faster, blasting to 60 mph in as little as 2.3 seconds (a feat that requires drag slicks, not street tires), and running the quarter mile in 9.9 seconds! A 2019 Corvette ZR1 (755 hp) can hit 60 mph in 2.9 seconds and run down the quarter mile in about 10.6 seconds on pump gas. As for the 2020 Mustang GT500 (760 hp), it will accelerate from 0 to 60 mph in about 3.3 seconds and run a quarter mile in about 10.7 seconds on street tires.

As impressive as these numbers are, they are mostly for bragging rights since few street driven vehicles need this kind of horsepower or acceleration. Although some of these cars will spend some of their time on a road course or drag strip, most will never be driven on a race track. What's more, once an engine's power level exceeds about 500 hp, traction becomes a major challenge. On dry pavement with soft rubber compound tires, the rear wheels can usually maintain traction if the vehicle is driven normally. But on damp pavement or a wet surface, these cars handle like hockey pucks and have minimal traction at best. Even with traction control, a really high horsepower vehicle can be tricky to drive on public roads.

Using Horsepower and Torque Numbers to Estimate Acceleration

There are all kinds of complicated formulas for estimating how fast a vehicle will run a quarter mile. Factors that influence quarter mile speeds include peak engine horsepower/torque and the overall weight of the vehicle, and also traction (which is really hard to estimate), transmission and differential gear ratios, rear-wheel drive or all-wheel drive, weight distribution (front/rear ratio), and even aerodynamic wind resistance. How fast a vehicle actually runs a quarter mile and how fast it could theoretically run a quarter mile are usually two different numbers. Most vehicles fall short of their theoretical best because of excessive wheel spin, loss of traction, clutch slippage or poor driving skills.

Power- To-Weight Ratio

The best (and simplest) predictor of how fast a vehicle can accelerate is its power- to-weight ratio.

The lower the ratio, the better because there is more horsepower to move each pound of vehicle mass.

<u>Power-to-weight ratio = Vehicle Weight divided by Horsepower.</u>

Power is what the engine delivers to the drive wheels on a chassis

Weight is the **Curb Weight** of the vehicle, plus the weight of the driver.

Example: A 5000 lb. SUV with a 300 hp engine will have a power-to-weight ratio of 16.7.

Example: A 4000 lb. car with a 400 hp engine will have a power-to-weight ratio of 10.

Example: A 1600 lb. Indy race car with a 700 hp engine will have a power-to-weight ratio of 2.28.

Example: A 2300 lb. Top Fuel dragster with 10,000 hp engine will have a power-to-weighty ratio of 0.22.

Which of these vehicles will accelerate the fastest? Obviously, the Top Fuel dragster because it has the best power-to-weight ratio. A Top Fuel dragster can blast from 0 to 60 mph in 0.8 seconds! It can also run a quarter mile (which has been reduced to 1000 feet for Top Fuel dragsters to keep speeds down for safety) in less than 4 seconds! The record for an actual quarter mile is 3.7 seconds at 330 mph!

<u>Improving Your Power-to-Weight Ratio</u>

You can improve acceleration times by increasing horsepower, reducing weight or both.

Bolt-on engine modifications such as a performance camshaft, larger throttle body or carburetor, better flowing heads, and a less restrictive exhaust system can add horsepower to any engine. Power adders such as nitrous oxide, a turbocharger or supercharger can boost horsepower even more.

Replacing heavy steel body panels with lighter weight aluminum, fiberglass or carbon fiber panels can shave off excess weight.

Changing the gear ratios in the transmission and/or differential can multiply torque for faster acceleration.

Installing soft compound tires or drag slicks can help your vehicle make better use of the power it makes by minimizing wheel spin for better traction.

Traction if often the limiting factor as to how quickly a vehicle can accelerate from a dead stop. Front-wheel drive cars are at a disadvantage because weight transfers rearward when accelerating hard, causing the front wheels to lose traction and spin. Rear-wheel drive vehicles are better IF the vehicle is not too nose heavy and there is adequate weight over the rear wheels to help maintain traction. The best stetup is all-wheel drive (AWD) because all four wheels can provide drive traction instead of just the front or rear tires.

Estimating Quarter Mile Times Using Power-To-Weight Ratio Numbers

The following estimates for various power-to-weight ratios are based on some fancy math using a scientific calculator, some industry accepted equations and minimal wheel spin.

Quarter Mile Elapsed Time = the cube root of the power-to-weight ratio times 5.825.

P/W ratio	Estimated E.T. (seconds)
16	14.68
15	14.36
14	14.04
13	13.69
12	13.33
11	12.95
10	12.55
9	12.11
8	11.65
7	11.14
6	10.58
5	9.96

4	9.25
3	8.40
2	7.34
1	5.82
0.5	4.02

NOTE: The above numbers are estimates only (your results may vary). Some vehicles with these power-to-weight ratios may actually run faster times provided they have great traction, while others with the same power-to-weight ratio may run slower times because of traction losses and poor driver skill.

Electric Vehicles and Torque

One of the major differences between internal combustion engines and electric motors is that electric motors develop peak torque right from the start while an IC engine slowly builds torque with RPM. That's why an electric car like a Tesla can be very quick off the line. The electric motor and battery pack on a Tesla Model S P100D with Ludicrous Mode can generate 588 hp (438 Kw) with an incredible 920 lb.ft.(1247 N.m) of torque! Those kind of numbers with all-wheel drive can push the 4900 lb. car from 0 to 60 mph in 2.7 seconds, which beats a Dodge Hellcat, Corvette ZR1 or Mustang GT500!

Railroad locomotives use electric motors to drive the wheels because it takes a LOT of torque to get a train moving from a dead stop. A locomotive may have a 3000 to 4000 hp diesel engine that is only used to drive a DC or AC generator. Current from the generator is then routed to the electric motors to turn the wheels. The drive motors can generate up to 60,000 lb.ft of torque to get the train moving. How fast a locomotive accelerates depends on the number of cars it is pulling and how many tons of cargo they are carrying. With no cars behind it, a locomotive might hit 60 mph in 20 seconds or less. With a long string of heavily loaded cars, it might take several minutes to get up to speed. And for a really long heavy train (say 100 or more fully loaded cars), it might take several locomotives connected in series to pull the train.