THE FUNDAMENTALS OF ENGINE PERFORMANCE

HERE'S A FRESH APPROACH TO THE BASICS BEHIND THOSE QUICK ETs AND FAST SPEEDS AND JUST WHAT THOSE DYNO HORSEPOWER AND TORQUE CURVES MEAN!

Any study of the basic fundamentals of automotive engines should start with *performance.* By performance we mean the maximum horsepower and torque the engine will develop, the RPM at maximum power and torque, the flatness of the torque curve, the "peakiness" of the power curve, friction losses inside the engine, accessory losses outside the engine (fan, pumps, alternator, mufflers, etc.) and a dozen other factors. After all, isn't performance just about the whole name of the hot rodding game? This is what the engine actually *does* for you, the acceleration and speed it produces when you hook it up to the transmission. This is the payoff of all your tuning and modifying. We'll find out later *how* it does it and *why.*

Any discussion of engine performance has to start with a thorough understanding of horsepower and torque.

The technical definition of the term "power" is the *time rate of doing work,* in other words how quickly the engine can do a given amount of work. If you lift a load of 50 pounds up a distance of three feet, you have done 50 x 3 = 150 ft.-lbs. of work. But we would have to know how quickly you lifted it to determine the power you developed. One horsepower is defined as 550 ft.-lbs. of work *per second.* So if you lifted that 50 lbs. up three feet, in say, two seconds, you would be doing 75 ft.-lbs. of work per second, or roughly one-seventh of a horsepower. It's as simple as that.

This is how horsepower determines the potential performance of your car. The load in this case would be the weight of the car and the drag (wind resistance, friction, etc.) that's holding it back. The distance factor would be the number of feet the car moves forward in one second. Let's just say the total drag (load) of the car is 1000 lbs. at a speed of 150 mph, or 220 feet per second. This drag would be made up of wind resistance on the body, tire rolling resistance, and friction in the bearings, gears, etc. In other words the engine would have to do the equivalent of lifting a load of 1000 lbs. up a distance of 220 feet in one second. This would be 220,000 ft.-lbs. of work per second. Divided by 550 it would be exactly 400 hp. If the engine developed only, say, 390 hp the car couldn't reach 150 mph, regardless of the gear ratio or tire size or anything else.

Now "torque" is nothing more than a force, actually the *twisting* force that the engine exerts on the flywheel (which is transmitted through the transmission to turn the rear wheels). It's the same type of twisting force you would exert on a wrench or crank handle. Torque is measured in lb.-ft. In other words a force of ten lbs. on the end of a crank handle two feet long would be 10 x 2 = 20 lbs.-ft. of torque. A modern big-inch automotive engine can exert anywhere from 400 to 500 lbs.-ft. of torque.

Now this is important: torque is related to horsepower by assuming that the torque force acts on the end of an imaginary crank one foot long. This means that the force would act through a distance of 6.28 feet (the circumference of a circle of one foot radius) each time the engine revolves once. This would give you the ft.-lbs. of work per second when you know the RPM. If you want to be technical, horsepower is calculated by multiplying torque by RPM, and dividing by 5252. In other words 380 lbs.-ft. of torque at 4500 rpm would be 326 hp.

In fact this is how an engine is tested to determine the horsepower. You can't measure horsepower directly. What you do is measure the torque at a certain RPM, and then calculate horsepower on a slide rule with the above formula.

This is done by mounting the engine on a dynamometer. A "dyno" is nothing more than a device that will *load* the engine and dissipate the power in the form of heat. Most dynos use either water turbines or electric generators as loading devices, with the load adjusted by varying the amount of water in the turbine or changing the resistance load on the generator. In either case it's simple to get rid of the high heat generated. Then the loading unit is mounted in some type of ball bearing cradle so it is free to rotate. Of course if this rotation weren't constrained the dyno would just spin around when the engine put power into it, and it wouldn't absorb any power. But by hooking up the dyno to a spring scale with a lever arm a certain length, the torque reaction of the dyno in its cradle can be accurately measured. And this, of course, is the same as the torque input from the engine. The horsepower can be calculated directly from the scale reading on the dyno.

The engine is tested by adjusting the load of the dyno to hold the engine at the desired RPM (with throttle wide open), taking the torque reading, then reducing the dyno load to let the engine speed up to the next test point. Readings are usually taken every 200 to 500 rpm over the full speed range. These readings let us plot out the horsepower and torque curves on a graph.

You're all familiar with the shape of typical horsepower and torque curves for an automotive engine. Some are shown here. Note that the power curve starts out low at low RPM, rises swiftly as RPM goes up, then finally curves over into a rounded peak at the top of the speed range. At higher speeds the horsepower falls off. The torque curve is entirely different. Torque is fairly high at very low engine speeds, and the curve rounds up into a peak near the middle of the speed range, then falls off fast at higher speeds. Most torque curves tend to be quite flat in the middle. This is desirable, as the engine has more constant pulling power over a broad RPM range.

Some people ask how the power curve can be going up when the torque curve is going down. It's a matter of rates. Since horsepower is calculated by multiplying torque times RPM, then if torque is falling off at a slower rate than RPM is going up, the horsepower keeps going up. Where torque falls off at the same rate as RPM goes up, this is the peak of the horsepower curve. Nothing mysterious here.

A little thought will show why the torque curve is shaped the way it is, and since the horsepower curve is calculated from the torque curve, you can figure that shape out, too. You would expect the torque to reach its highest point in the middle of the speed range because this is where the engine runs most efficiently. It's breathing in a full gulp of fuel and air on each suction stroke, combustion is optimum, and friction losses inside the engine are quite low. Everything is right at medium speeds. But as engine speed goes up things get worse. Breathing falls off because of restriction through the carburetor, in manifold passages, ports, and through the narrow opening around the edge of the valve. The engine gets less and less fuel and air as RPM goes up. And of course your friction losses in the engine are shooting up. Friction in bearings, gears, between piston rings and cylinder walls, etc., increases roughly as the *square* of RPM. In other words it would be about *four times* as great at 4000 rpm as at 2000. So with the friction shooting up like this, and the breathing falling off, it's no surprise that the torque curve drops off fast at higher speeds. The horsepower keeps going up after the torque starts to fall off, but eventually that peaks out and falls off also.

Just where your maximum horsepower and torque come on the RPM scale is a very important factor in engine performance. This can vary all over the place. You always have to remember that the engine is fighting increased friction and reduced breathing as RPM goes up. And friction, obviously, would depend a lot on the *size* of the engine. Bigger bearings, longer stroke travel and heavier moving parts would all tend to increase friction. So we would expect big engines to peak out their horsepower and torque at much *lower* RPM's than small engines. And this is the case.

For example a tiny 12-cylinder, 183-cubic-inch Formula I racing engine in Europe, with four valves per cylinder, fuel injection, wild cams and every goodie to improve breathing, might peak its horsepower as high as 10,000 rpm. Peak torque would be in the range from 7000 to 8000 rpm. An engine like this would fall flat on its face even at 5000! But now take a big American NASCAR racing engine like the new stagger-valve 429-cubic-inch Ford. With much bigger cylinders and more friction than the small Formula I engine, it would peak its horsepower close to 7000 rpm, with peak torque in the 4000-5000 range or maybe a bit higher. The breathing efficiency here might be almost as good as the small engine, but fighting all the friction is a lost cause. Small engines almost always put out more power *per cubic inch* than similar big engines. In the above case the 183-cubic-inch Formula I engine might pull 420 hp at 10,000 rpm, or about 2.3 hp per cubic inch. The big Ford might get 650 horses at 7000, or 1.5 hp per cubic inch. See what we mean?

For this same reason you can get more power out of a given cubic inch size by using more cylinders. The engine with more cylinders would have *smaller* cylinders, and this would reduce friction from the shorter stroke and smaller bore, since piston friction is the biggest factor in overall engine drag. A good example of this would be the turbo-supercharged Indianapolis engines. The four-cylinder turbo Offy pulls 625 hp at 8000 rpm, while the new turbo Ford V-8 gets around 700 hp at 9500. And yet both engines have similar compression, breathing, fuel and blower pressure. The difference is largely in friction.

Another interesting phenomenon is the effect of engine size on relative power and torque. A smaller engine will inherently develop more horsepower per cubic inch because of the lower friction, while a big engine will develop more torque in the medium speed range because it's burning more fuel each revolution. For example you might have a small 250-cubic-inch engine that might develop 200 hp at 5000 rpm and maximum torque of maybe 250 lbs.-ft. at 3000. This would be with fairly mild passenger car cam timing and carburetion. Now a larger 300-cubic-inch engine with the same degree of camming and carburetion might put out the same 200 hp maximum, but at 4500 rpm instead of 5000. And the peak torque would be closer to 290 lbs.-ft. at 2500 rpm.

The smaller engine is actually more efficient. But the bigger engine would *feel* peppier in the car. It would be more flexible over a broader RPM range, and the response at very low speeds in city traffic would be better. American car designers favor big cubes and high torque, with current engines in the heavier cars going over 450-cubic-inches and 500 lbs.-ft. of torque.

It's also interesting to compare the maximum horsepower and torque when you use different equipment on the same basic engine. The late 327-cubic-inch Chevrolet engine was used in many different forms and stages of tune in various car models. Here is how the factory advertised horsepower and torque ratings varied with different equipment:

	HORSEPOWER	TORQUE
Two-barrel carb; low comp.; cool cam; small valves	210 @ 4600	320 @ 2400
Four-barrel carb; hi comp.; medium cam; med. valves	275 @ 4800	355 @ 3200
Larger four-barrel carb and manifold	300 @ 5000	360 @ 3400
Same carb; 11:1 comp.; hot cam; big valves	350 @ 5800	360 @ 3600

You can see from the above comparisons that the usual "speed equipment" – bigger carbs, manifolds, higher compression, hot cams, bigger valves – have a big effect on the peak horsepower and the peak RPM at which this power is developed. But they have little effect on actual maximum torque, only on the RPM where it comes in. Note that these hop-up changes above increased horsepower from 275 to 350, while increasing peak torque only from 355 to 360 lbs.-ft. But peak torque range moved up from 3200 to 3600 rpm. Some-times this type of hopping up will actually, reduce the maximum torque, while still putting the peak point up to a higher speed. Many of the tricks you do to boost peak power actually tend to kill mid-range torque. Best things for torque are *cool* cams, small valves, small carbs.

Of course there are definite limits to how high you can raise peak power and the peak RPM point by these hop-up tricks like hot cams, big carbs, big valves, etc. We still have to fight that friction. The better the breathing the more power we can develop in the cylinders to fight the friction, but eventually you reach a point where the horsepower has got to peak out and fall off.

This ultimate peak RPM point might be somewhere around 7000 to 7200 on a big 427-cubic-inch NASCAR-type engine, even with fuel injection and all the goodies. The new 429 NASCAR Ford peaks around 7200. The Chrysler 426 Hemi peaks below 7000. But now when you get into the smaller engines with less friction that peak RPM can go up. A small 265 or 283 Chevy, with three-inch stroke, can peak its horsepower as high as 7500 to 7700 rpm when everything is just right. The 302-cubic-inch Gurney-Weslake Ford that took second at Indy last year gave 535 hp at 7800 rpm on 20 per cent nitro. These figures, of course, assume razor-sharp tuning. The average backyard speed mechanic would get peak revs 500 to 1000 rpm below these figures with the same engines. And of course superchargers would raise them perhaps 500 rpm because you would be packing that much more fuel and air into the cylinders to forcibly overcome friction. "Blown" engines always peak their horsepower at substantially higher RPM's than the same engine without a blower.

Now we want you to be sure not to confuse this term "peak RPM". This is *not* the fastest speed the engine will turn. This ultimate maximum rev speed would be determined by your valve gear – how high you can wind before valve float or hydro-lifte "pump-up" -- or by the strength of the engine's bottom end, before you burn a bearing or throw a rod. But when we refer to "peak RPM" this means the revs at the peak of the power curve, where maximum horsepower is developed. Many engines will wind far beyong this point before valve float or bottom-end failure.

It might seem foolish to wind beyond the peak of the power curve, when horsepower is falling off. But actually the shape of the power curve above the peak is very important in many types of racing. You don't want power to fall off too fast, in other words have a "peaky" power curve. If you have broad, flat peak on the curve you can wind up to fantastic revs through the gears and get better times on the drag strip. Lots of small-inch Chevys that actually peak their power around 7000 rpm are shifted between 9000 and 10,000 on the strip! Proper selection of cam timing, port size and carburetion can help power above the peak. In fact this has been one of the most important areas of hot rod tech development in the last three years.

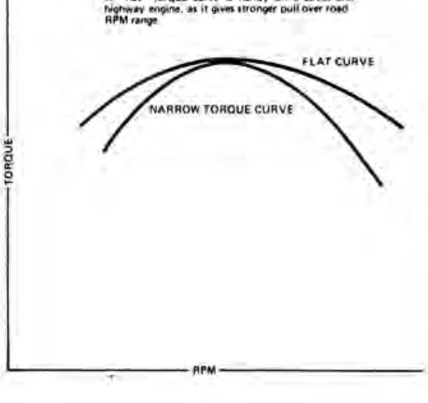
We've been talking a lot about internal engine friction in this article, and its effect on high-rev performance. But we have to remember there are many other "parasitic" losses on the engine that also increase with RPM, and the power developed in the cylinders has to overcome these drags just like the internal friction. We're talking now about the familiar external accessories on the engine, the pumps, the fan, the alternator, the mufflers. And then there are the internal parasites like the water pump, oil pump, camshaft drive, etc. The horrible part is that the power absorbed by most of these items tends tor increase as the *square* of RPM, just like friction. (In other words four times as at 2000.

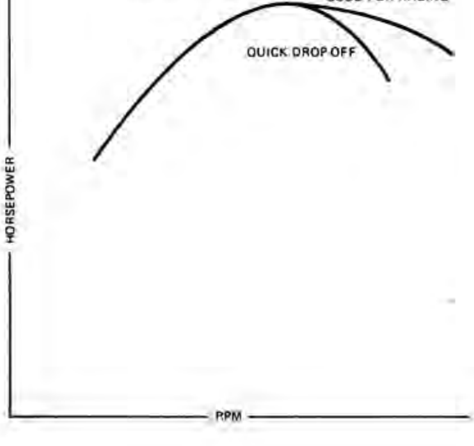
We don't think a lot of car fans realize just how rough these losses really are. The advertised horsepower and torque ratings on an engine don't include any of these losses except those right inside the engine like the oil pump, water pump, cam drive, etc. But there's plenty of loss outside. For instance a typical fan can rob you of 10 or 12 hp at 5000 rpm engine speed. (This is why special de-clutching fans are becoming popular on high-performance engines.) Power steering pumps and alternators can take one to three hp. An air conditioning compressor pulls eight to 10 hp most of the time. And when the engine breathes in the hot air under the hood of a car it robs power because the air is light, and you don't get as big a gulp on each suction stroke. Factory dyno tests are corrected to 60 degrees F. air temperature, where the average underhood temperature is more like 100 to 130 degrees. This means another loss of five to 15 hp from the advertised horsepower figure.

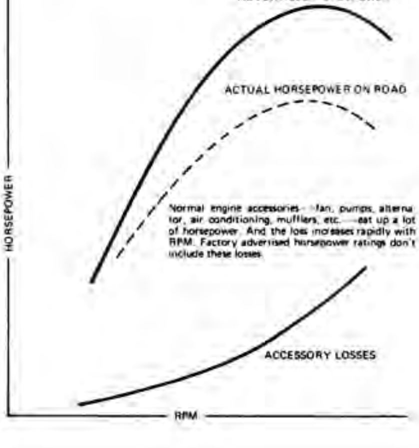
But certainly the worst robber of all is the muffler. Factor dyno tests are made with the exhaust going into a big venitlation duct where there is no restriction (except in the actual manifolds on the engine). But in the car the muffler sets up a high "back-pressure" that the pistons have to push against on the exhaust stroke. We've seen back-pressure test figures as high as *10 or 12 lbs per square inch* in stock single-muffler systems! That can lose you 30 to 50 horses right now. Factory dual exhausts systems (which are standard on most high-performance models) help quite a bit. But these leave plenty to be desire , too.

So you add it all up and you're going to lose probably an average of around 25 per cent of the factory advertised horsepower rating between the dyno and what your engine can actually do for you on the street. In other words if the engine carries an advertised rating of 250 hp, you can figure on maybe *190 horses* out on the street. And the peak RPM will be down 300 or 400 rpm from the factory figure. We have confirmed this with many accelerometer tests. Some engines are better than others in this area, of course. Chevrolet engines, for example, are noted for being rates conservatively. Actual power may be only 10 or 15 per cent below the rating in this case. Ford engines are more optimistically rates.

Well, so it goes. We hope you understand a little more about this business of engine performance now. We'll be talking a lot about it in the next few months.


A "flat" torque curve is handy on a street and highway engine, as it gives stronger pull over road RPM range.


A power curve that doesn't drop off too fast above the "peak" is good on a racing engine, where you wind up tight in the gears. Cam, carburetion and porting can help this.


Normal engine accessories—fan, pumps, alternator, air conditioning, mufflers, etc.—eat up a lot of horsepower. And the loss increases rapidly with RPM. Factory advertised horsepower ratings don't include these losses.