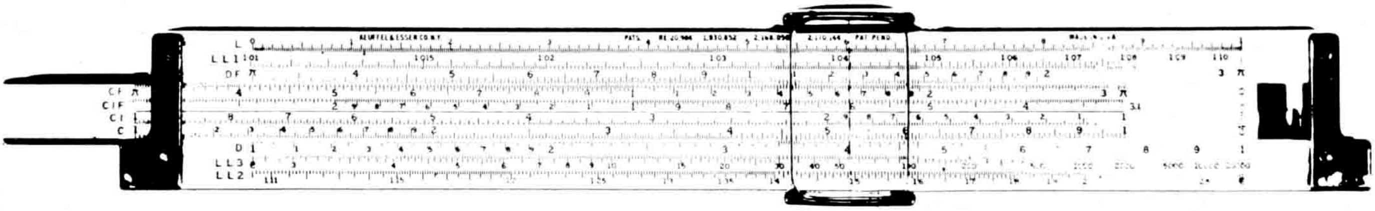


FORMULAS FOR CARNAUTS

BY ROGER HUNTINGTON

A Slide Rule Could Be the Motorist's Best Friend

SELF-PROPELLED VEHICLES are designed and built today on a pyramid of mathematics. Numbers tell the story. Consequently, every car enthusiast continually runs into simple mathematics problems (generally connected with performance) that scream for immediate solution.

Frankly, however, I was a little hesitant when the *Car Life* editors asked about this story. Formulas are a dime a dozen. Who has the ambition to work them out "longhand?" I wouldn't consider doing it, myself. The slide rule is the only answer if you want to really work on "car math." I've often thought it would be quicker to learn to work a slide rule than to work out one lengthy problem with pencil and paper. A decent slide rule represents a $5 to $30 investment that will last a lifetime.

Car enthusiasts frequently run into problems of piston displacement. The basic formula for figuring it is: Bore × bore × 0.785 × stroke × number of cylinders. By squaring the bore and multiplying by 0.785 you find the area of one piston top. Then multiply by stroke length to get the displacement of one cylinder—then by the number of cylinders to get the total.

Actually, the problem that comes up most frequently is how to figure the displacement when the bore and/or stroke are increased. There are simple ways to do this. For instance, displacement is proportional to the square of the bore: Divide the overbore by the original bore, square this number, then multiply by the original displacement. For example: your engine has 360 cu. in. and you have increased the bore from 4.00 to 4.125 in. Thus, 4.125/4.00 = 1.031; then 1.031 × 1.031 = 1.064; and 1.064 × 360 = 383 cu. in.

Stroke increases are easier. Here displacement is directly proportional to the stroke. Just divide new stroke by old stroke, and multiply by original displacement. If the original displacement is 354 cu. in. and stroke has been lengthened from 3.375 to 3.750, then 3.750/3.375 = 1.111; and 1.111 × 354 = 393 cu. in. If we have a problem where the bore and stroke are increased at the same time, it's easier to figure it with the original formula above.

The volume of a combustion chamber can be figured by dividing the displacement of one cylinder by the compression ratio minus 1. Thus a V-8 engine of 327 cu. in. has 327/8 = 40.9 cu. in. per cylinder. And the chamber volume with a compression ratio of 9.5:1 would be 40.9/8.5 = 4.81 cu. in. Cubic inches can be converted to cubic centimeters by multiplying by 16.4 (as there are 16.4 cc per cu. in.). Thus the cc volume here would be 16.4 × 4.81 = 78.9 cc.

Sometimes we want to know how much to mill off a cylinder head to bring the compression ratio up to a certain point. But we can't accurately determine the area of the combustion chamber opening without special instruments. So, we can get a rough idea if we can estimate this area. (Try to ►

HANDY FORMULAS

$$\text{CORRECTED SPEED} = \frac{3600}{\text{time in sec. for one mile}}$$

$$\text{ROAD SPEED} = \frac{\text{engine rpm} \times \text{tire diameter}}{336 \times \text{gear ratio}}$$

$$\text{ENGINE RPM} = \frac{336 \times \text{gear ratio} \times \text{mph}}{\text{tire diameter}}$$

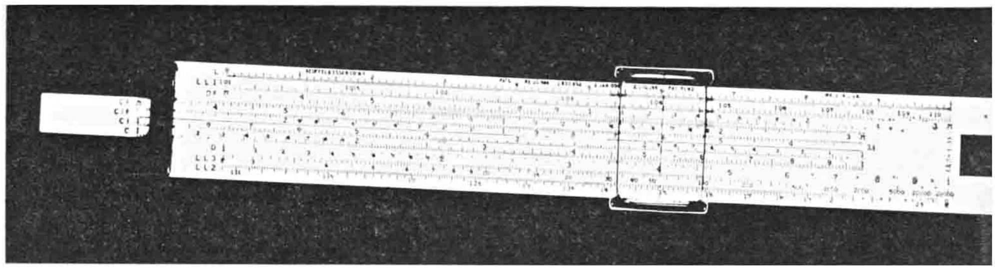
$$\text{ENGINE DISPLACEMENT} = \text{bore} \times \text{bore} \times 0.785 \times \text{stroke} \times \text{no. cyl.}$$

$$\text{DISPLACEMENT INCREASES} = \left(\frac{\text{overbore}}{\text{original bore}}\right)^2 \times \text{original displacement}$$

$$\frac{\text{new stroke}}{\text{old stroke}} \times \text{original displacement}$$

$$\text{COMBUSTION CHAMBER VOLUME} = \frac{\dfrac{\text{displacement}}{\text{no. of cyl.}}}{\text{compression ratio} - 1}$$

FORMULAS FOR CARNAUTS



picture it as an equivalent rectangle and multiply length by width.) Then, obviously, the volume removed by milling would be this area times the amount milled off. Also, it is necessary that the piston comes up very close to the top of the block to make this method applicable. No deep deck clearances. But let's assume that we want to mill enough off to raise the compression ratio of the above 327-cu. in. engine from 9.5 to 10.5:1. Now the required chamber volume with 10.5 ratio would be 40.9/9.5 = 4.30 cu. in. When we subtract this from the original volume of 4.81 cu. in. we come up with 4.81 − 4.30 = 0.51 cu. in. This is the volume that has to be milled out of the chamber. If we estimate the chamber opening area as, say, 7.6 sq. in., then we must mill off 0.51/7.6 = 0.067 in.

Another frequent problem involving compression ratio is how much the true ratio is raised when the piston displacement of the engine is increased. (Since this ratio is determined by both the cylinder volume and chamber volume, any increase in cylinder size without a corresponding increase in chamber size will raise the ratio.) A simple way to do this one is merely to divide the increased displacement figure by the original displacement, then multiply by the original compression ratio minus 1. This product, plus 1, will be the new compression ratio. Let's say we increase displacement from 327 to 352 cu. in., and the original ratio is 9.5:1. Thus 352/327 = 1.077, then 1.077 × 8.5 = 9.15. The final ratio is 9.15 + 1 = 10.15:1.

It's frequently handy to figure the engine rpm at a given road speed with a given gear ratio and tire size. Probably the simplest way to do this is to work with actual tire rolling diameter, which you can readily measure. Some error is introduced by tire expansion at high speeds. But this can be partially compensated for by measuring the overall standing diameter only for speeds up to maybe 75 mph. For higher speeds measure the free radius of the tire from the hub center to the top—then double this to get an idea of the effective rolling diameter when the tire has expanded under high centrifugal forces. (This is probably only true at speeds over 100 mph; you could use an intermediate value between 75 and 100.)

The formula for figuring rpm is: 336 × gear ratio × mph divided by tire diameter. For example, with a tire diameter of 28 in., axle gear ratio of 3.36 and the rpm at 75 mph, road speed would be 336 × 3.36 × 75/28 = 2680. Of course this formula can be used for the other forward gears by using the overall gear ratio in that gear—obtained by multiplying the axle ratio by the ratio in the transmission. Thus with the rpm at 75 mph and this same axle ratio and tire size, but in 3rd gear (4-speed transmission) with a 1.41:1 ratio, we would use the overall ratio of 3.36 × 1.41 = 4.74:1 in the formula. This resulting rpm would be 3780. In fact we could have gotten this same answer by merely multiplying the rpm at 75 mph in high gear (2680) by the transmission ratio in 3rd (1.41), and would come up with the same 2680 × 1.41 = 3780 rpm.

This gives us a clue to this business of figuring the rpm drop when the gears are shifted. This is a very simple, straightforward problem. Let's say we have the new Chevrolet 4-speed transmission with ratios of 2.56 (low), 1.91, 1.48 and 1.00, and we shift at 5500 rpm. Thus on the shift from 1st to 2nd the rpm will drop to 1.91/2.56 × 5500 = 4100. On the 2nd-to-3rd shift it will drop to 1.48/1.91 × 5500 = 4260. On the 3rd-to-4th it would drop 1.00/1.48 × 5500 = 3720. It's just a matter of dividing the transmission ratio in the next higher gear by the ratio we're shifting from, and then multiplying by the rpm at shift point.

Another frequently needed answer is the road speed at a given engine rpm, with a given overall gear ratio and tire diameter. In this case we can just convert the above formula. That is, this road speed would be: rpm × tire diameter divided by 336 × gear ratio.

For example, let's figure the rpm in low gear with the above Chevrolet 4-speed at an engine speed of 5500 rpm, with 3.70 axle gears and 28-in. tires. The overall ratio would be 3.70 × 2.56 = 9.47:1. Then this answer would be: 5500 × 28/336 × 9.47 = 48.4 mph. The car speeds in the higher gears could be readily figured by dividing ratios and multiplying by 48.4 mph. The car speed in 2nd gear at 5500 rpm would be 2.56/1.91 × 48.4 = 64.9 mph. In 3rd gear, 2.56/1.48 × 48.4 = 83.7 mph.

The swift increase of freeway mileage with well-defined mile markers along the sides has made it very convenient and easy to determine a car's speedometer error. This is the way to do it: If we want to determine the error, say, at 60 mph, the car is driven for the one mile distance at an exact 60 mph indicated on the speedometer, and timed carefully with a stop watch. This 60 mph calibration is very easy, because one mile at this true speed takes exactly 60 sec. Thus every second off 60 sec. on the watch is approximately 1 mph error on the speedo. For instance if the watch says 63 sec. after you have traveled the mile, the speedo is reading about 3 mph fast. It has taken longer than one minute to go the mile, so the true speed is actually about 57 mph.

A more accurate way to determine the true speed is to divide the seconds required to go one mile into 3600. Thus 3600/63 = 57.15 mph. This extra accuracy is probably not required for the 60-mph calibration. But we'll need the formula for other speeds. Let's say we want to determine the error at 80 mph. The watch says 46.6 sec. Thus the true speed is 3600/46.6 = 77.2 mph. The speedometer is a bit less than 3 mph fast at 80 mph. Thus a true 80 mph would call for about 83 indicated. We can check this by timing the car for a mile at an exact 83 mph indicated. The stop watch should stop at just about 45 sec., which is the time required for the mile at a true 80 (this can be determined by dividing 3600 by 80, to get 45).

Caution: When timing between mile markers on a freeway try to avoid using road sections with curves. Apparently they measure these distances right down the centerline of the road, so a car would have to straddle the center to get accurate distances around curves—whereas we can stay in the right lane on the straightaway. This may seem like a small factor; but we have had a lot of trouble getting consistent speedometer calibrations on curved roads.

Car Life readers should know that there is no simple equation with which we can calculate the horsepower required to move a given car down a level road at a given speed. There are too many factors involved, and they are related to each other and to car speed in complex ways. However, we can still do a little generalizing. For instance, we can assume average values for the wind drag coefficient and driveline efficiency, as these values don't vary widely on the average passenger and sports car. Tire rolling resistance will generally run 40 to 50% of wind drag in the range from 90 to 150 mph (with typical tire pressures). We can't generalize much on frontal area although it is closely proportional to the car height × width. Thus here is a very "generalized" equation for estimating car horsepower requirements at various speeds on a level road:

$$\text{bhp} = \frac{\text{height x width x mph}^3}{36{,}000{,}000}$$

As an example, let's estimate the power for a typical American medium compact car with height of 54 in. and width of 73 in. At a road speed of, say, 110 mph, the bhp required would be: 54 × 73 × 110 × 110 / 36,000,000 = 145 bhp. A small sports car, 50 × 55 in., at 80 mph would require 39 bhp by this formula. Sound reasonable?

The above formula can be converted to give a top speed estimate for a given car with a given amount of horsepower—though this would require the extraction of a cube root, which is strictly slide rule stuff. Here's the conversion:

$$\text{mph} = \sqrt[3]{\frac{\text{bhp x } 36{,}000{,}000}{\text{height x width.}}}$$

The above small sports car (50 × 55 in.) with, say, 110 bhp at the clutch, should have a top speed of about:

$$\text{mph} = \sqrt[3]{\frac{110 \text{ x } 36{,}000{,}000}{50 \text{ x } 55}} = 113 \text{ mph.}$$

Keep in mind that the bhp figures used in this formula are supposed to be true bhp available at the clutch. Some foreign engines are rated with accessories and installation losses included, so we can generally take good stock in those advertised ratings. But beware of the SAE ratings on Detroit engines. These ratings include no accessories, a manual spark advance and mixture control, open exhaust, and then correction to 60° F. air temperature. We can generally knock off anywhere from 15 to 40% from the advertised rating to get true bhp at the clutch. For instance, for a full-sized car (55 × 78 in.), a true top speed of 115 mph is common with 300 rated bhp. This figures out to 182 bhp by the above formula.

It is also obvious from this formula that the power required to move a car increases roughly as the cube of the speed. Thus, to increase our top speed from, say, 100 to 120 mph, we would need to increase the power by 1.2 × 1.2 × 1.2 = 1.728 times. In other words, a 73% increase in bhp is needed to get the extra 20 mph. This is why high cruising speeds require so much fuel—and why the true 150 mph sports car is a rare bird.

The classic Newtonian acceleration formulas are not much good in automotive work. They all assume a constant rate of acceleration and this condition is pretty unusual on the road or drag strip. The acceleration rate is continually changing. Thus the classic formulas for distance covered in a given time and velocity at the end of a stated time period just don't hold.

However, research has uncovered one rather interesting relationship that lends itself to slide-rule analysis. That is, the terminal speed at the end of a standing-start ¼-mile increases as the cube root of the bhp-to-weight ratio. And, of course, if weight stays constant, the speed will increase as the cube root of the bhp. Thus, if true bhp is increased by 20%, say, the increase in terminal speed would be proportional to the cube root of 1.20 or about 6%. Or, let's say we fiddle with the engine and get the trap speed up from 82 to 84 mph. This is an increase of 84/82 = 1.024 times. When 1.024 is cubed, the percentage increase in power is about 8%.

Trap speed is inversely proportional to the cube root of weight. If the weight is reduced 15%, we would take the cube root of 0.85. This equals 0.947—which is what we would divide the original trap speed by. An original speed of 82 mph would be scaled up to 82/0.947 = 86.6 mph.

Then there's that elusive *Car Life* Wear Index which seems to bother new readers. To determine this, an admittedly arbitrary measure of potential service life, take engine revolutions per mile × stroke × 2, divide by 12 to get piston travel in feet per mile; then multiply piston travel × engine revolutions per mile and divide by 100,000 to get the workable figure used as Wear Index. For example, that 327 Chevrolet with a 3.36 axle ratio would work out 2555 × 3.25 × 2 = 16,606/12 = 1383; then, 1383 × 2555 = 3,533,565/100,000 = 35.3 Wear Index. The lower this resulting index, the less will be the engine wear, while a higher figure means more friction.

Well, this is getting pretty sticky . . . the best advice is still to get busy with a slide rule. ■