Compression Ratio Explained

When restoring vintage Corvette engines, care must to be exercised in machining and selecting components to ensure a compression ratio that yields maximum detonation-free torque and power with available premium gasoline.

Static compression ratio (SCR) is the ratio of the *swept-plus* clearance volume to clearance volume. The number 10:1 means that the clearance volume at **top dead center** (TDC), which is the total combustion chamber volume, not just the head chamber volume, is one-tenth the total volume with the piston at bottom dead center (BDC). The higher the compression ratio, the more torque/power the engine will produce across the entire operating range, and peak torque is basically a function of displacement and SCR. At any given engine speed, volumetric efficiency and internal friction come into play to determine torque at that particular speed. And all other things being equal, a 10:1 SCR will produce about 5-10 percent more torque/power across the operating range than 8:1 and also deliver 5-10 percent better fuel economy.

Dynamic compression ratio (DCR) is the ratio of the total volume with the piston at the point the inlet valve closes (rather than BDC) to the clearance volume at TDC. Thus, for a given SCR, the later the inlet valve closes, the lower the DCR, which means the engine will tolerate a higher SCR. This is why special high performance (SHP) engines with their relatively late closing inlet valves have higher SCR than base engines. But there is no "industry standard" way to compute DCR. Some calculators use the SAE valve closing point, which is .006" valve lift, and some use an arbitrary number of degrees after the .050" closing point or some other methodology that may not even be specified. So DCR calculations are neither exact nor consistent. DCR is not a go/no-go criterion – just a general guideline.

The limiting factor in compression ratio is detonation, which is the spontaneous and instantaneous reaction of the unburned fuel-air mixture before it is consumed by normal flame front propagation. Octane number is an indication of a fuel's resistance to detonation, and the best currently available unleaded premiums are 93-94 PON or Pump Octane Number, which is the arithmetic average of Motor Octane Number and Research Octane Number. The difference between MON and RON is called the fuel's sensitivity, and it is generally in the range of 8-10. So today's 93-94 PON is equivalent to 97-99 RON, which is nearly the equal of sixties' vintage leaded premiums that were generally in the range of 98-100 RON. (Super Premiums of that era were slightly over 100 RON.) California and some other areas in the country only have 91 PON premium fuel, so the equivalent RON is no more than about 96, and Californians may want to keep SCR up to a quarter point below the recommended maximums for various OE configurations listed below.

The advertised SCR of early 327/300s is 10.5:1, but this was reduced to 10.25:1 in 1967 because of the slightly larger (about 1.5 cc) 462 head chamber volume that resulted from the elimination of the small quench zone on the spark plug side of the previous 461 heads. The as-built SCR of Corvette engines of the era are typically about 0.5 point lower than advertised, primarily because *deck clearance/deck height* is usually higher than the nominal blueprint values of .025"/9.025". Also, beginning as a running change during the '62 model year, SHP/FI engines were double gasketed, at least through the '63 model year, to reduce customer detonation complaints, but it's not clear how long this practice lasted. So most vintage Corvette engines will operate without significant detonation on 91-93 PON premium fuel with, at worst, a slight reduction in initial spark advance or slowing the centrifugal spark advance curve.

The 3830711 small-block service head gasket is .026" thick, while the OE Flint-installed 3783631 gasket (which was only available in service until circa 1963 when it was replaced by the …711) is only .018" thick. If a head was ever removed and reinstalled using an OE service replacement gasket after 1963, the compression is about 0.2 below the original build. Most engines are rebuilt with thicker composition gaskets, so when using exact OE replacement pistons, the actual compression may end up as much as a full point lower than the OE advertised value!

For this reason, it is very important to take the required measurements and run the calculations to compute the actual as-built compression ratio. You don't want detonation, but neither should you leave anything on the table. I see a lot of advice that recommends lowering compression ratio as if the only available fuel was unleaded regular. This is nonsense!

Anecdotal evidence indicates that 300-HP engines will operate detonation free at about 9.8:1, which is about what the maximum true SCR was when engines left Flint with the *thin head gasket*. This will drop to about 9.6 if you merely remove the head and replace the .018" Flint gasket with the .026" service replacement gasket. Duntov and L-79-cam engines will accept 10.25 and 30-30 and LT-11 cam engines can tolerate 10.5:1. The evidence I have for big blocks is scant, but I believe 10.0:1 is acceptable for L36/68 and 10.25 for SHP versions with the mechanical lifter camshaft. These *true SCRs* are obtainable with the OE pistons and judicious head gasket selection even if the block deck and head surfaces have been machined.

The illustrated engine is a base '67 300 HP that is being restored with a custom design low overlap camshaft that has a very late closing inlet valve, and the target true SCR is the range of 10.25-10.5:1. The low overlap yields OE 300-HP idle characteristics, and the late closing inlet valve in conjunction with massaged original 462 heads and the high compression will yield considerably more top end power and an extended useable power bandwidth.

Prior to disassembling the short block, the as-built measurements must be made. These include deck clearance for each cylinder and head gasket compressed thickness. These data, along with published piston and nominal head chamber volumes (assuming the heads show no evidence of chamber grinding and the mating surface has not been milled), can be used to compute the SCR range as it was before disassembly.

Deck Clearance is the distance at TDC between the piston *crown* (the machined flat surface at the top of the piston exclusive of any dome, dish, or valve clearance notches) and the block deck. In this case the *deck clearance* measurements varied from 0.025" to 0.031" among the eight cylinders. The nominal .025" blue print OE *deck clearance* for all 327s is derived by subtracting the sum of nominal crank throw radius (half the stroke, 1.625"), nominal connecting rod length (5.700"), and piston compression height (1.675", the distance from the center of the wrist pin to the crown) from nominal blueprint block *deck height* (9.025"), which is the distance from the crankshaft centerline to block deck. (OE 350s also have .025" nominal deck clearance, which is achieved with 1.560" piston compression height.) Be sure you understand the difference between *deck clearance* and *deck height*, and do not confuse them.

Setup for checking deck clearance. In this case the clearance of the original Flint-built engine is being checked prior to disassembling the block. It will be checked again during the assembly phase with the new KB157 pistons that have a specified compression height .003" greater than the OE pistons. All other things equal, the measured deck clearance of the newly assembled short block should be .003" less.

Analyzing the deck clearance data for all cylinders will tell whether each deck is parallel to the crankshaft axis and whether or not both decks are equal height. Since crank throw radius, rod length, and compression height are closely controlled dimensions (+/- .001" or less), any significant deviation from nominal *deck clearance* is usually due to *deck height* deviation from the nominal 9.025", and they are often high by up to .015".

With proper care, deck clearance measurements should remain within a thousandth or two of true, and if the deck clearances along a bank show no obvious "slope," then boring the cylinders using common boring equipment that indexes off the deck will result in good bores that are perpendicular to the crankshaft axis. If any slope is indicated, find a machine shop with boring equipment that indexes off the crankshaft axis, which is less common. If one deck averages more than a few thousandths higher than the other, different thickness gaskets on each side can be employed to equalize compression ratio. Commercially available head gaskets range in thickness from .015" to over .050" in five- to ten-thousandth increments. If the left deck *only* is high, it can be machined down without any effect on Flight judging because there are no ID numbers or tooling marks to observe and judge on the left deck.

John McRae built a tool using a machined bar that is set up to mount a dial indicator. The indicator can be used to find the exact TDC point. (Once TDC is accurately located, tap the piston to zero out any bearing clearance.) The indicator dial is then zeroed on the deck and moved over to the piston crown to measure deck clearance. Care must be taken to ensure that the piston crown is square in the bore as the slight skirt clearance can allow tilt, especially on SHP engines whose forged pistons should be installed with about .0035" clearance compared to about .001" for cast pistons. The deck clearance should be the same on each side of the wrist pin or the piston is not square in the bore. It is a good idea to go around at least twice and look for consistency in the data sets, which is a good indication of accuracy.

Another way to measure with simpler tools is to use a machinist's bar or a known accurate straight edge and two feeler gages. After using a dial indicator to find TDC, if the same size gauge fits between each side of the crown and the bar, the piston is square in the bore, and you should have an accurate measurement. The base engine flattop pistons are easy to measure. SHP engines are a little tougher because of the domes, but there is a machined ring around the outside of the crown and this is the piston surface for gauging deck clearance.

The machinist's bar and a .0015" feeler gauge can also be used to measure flatness of the block deck and head mating surfaces. The surfaces are flat if the same force is required to extract the .0015" feeler gauge from between the bar and surface at any point along the bar. Measurements should be made between corners including the diagonals. If surfaces pass this flatness test, an OE type shim gasket will seal.

The measured <u>head gasket thickness</u> was .018", which indicates that this was the original Flint-installed head gasket, and the gasket cylinder bore opening measured 4.08". The <u>head chamber volumes</u> were measured using the illustrated setup (Figure 2). Measuring head chamber volume is explained in many How to Hot Rod/Rebuild… books, and is a relatively simple operation for the amateur restorer.

Once you have accurate measurements for (1) original *deck clearances*, (2) *gasket thickness/cylinder opening diameter* and accurate dimensions or specifications for (3) *head chamber volumes*, and (4) *piston volume*, which can usually be gathered from published specifications (many of which are online), you can compute the original nominal compression ratio and range. In prehistoric times I had to do the arithmetic with a calculator (and even a slide rule), but nowadays I use a Web-based calculator, http://www.csgnetwork.com/compcalc.html, that accepts measured values/specifications without the need for any unit conversions.

From these initial SCR calculations, you can proceed with what-ifs. What is the SCR with a different thickness gasket or a piston with a different volume or compression height? Although there are some discrepancies in published specifications, I use –5 cc for the valve relief notch volume of the OE 300-HP pistons. Be careful about piston volume algebraic signs. Even though these notches add to total clearance volume, they are entered in the above calculator as a negative number, and the 327-SHP piston's 5.3 cc net dome volume should be entered as a positive number. Also, beware that some piston manufacturers use different conventions. Sealed Power/Speed Pro OE replacement pistons from Federal Mogul express a dome such as on the SHP pistons as a positive number. Keith Black pistons express a net dome as a negative number. Be certain you understand the piston manufacturers convention and reverse the sign if necessary–as is required with KB pistons–for input into the calculator.

Homemade apparatus for checking head chamber volume. The equipment was purchased at a lab supply house, and the fluid is denatured alcohol with food coloring dye added.

Check it out. Input your direct measurements/specifications, and the calculator does all the math to double-precision accuracy! Run a test case for a nominal '67 300-HP engine .025" deck clearance, .018" x 4.08" gasket, 62cc head chamber volume, and –5 cc dome volume to account for the piston clearance notches. Then try the same year L79, same deck clearance and gasket, but increase head chamber volume to 64cc and use +5.3 cc piston dome volume. Then for either configuration, increase the deck clearance by five or ten thousandths to simulate typical OE blocks as machined by Flint, and increase gasket thickness in five to ten thousandths increments to get a feel for the effect. Also change cylinder head chamber volume by 1-2 cc. You will see that small changes in these parameters have a significant effect on SCR!

If you plan to restore an OE engine to OE specifications, including the same camshaft, and it didn't detonate before the rebuild, there is no reason to lower the compression ratio. Most commercial rebuilders use thick composition gaskets, so you typically end up with considerably less compression than OE even if OE replacement pistons are used, and this will cost you performance and fuel economy!

Use the SCR calculator to select components to achieve the target SCR range, and upon assembly take all the measurements again. Run them through the calculator to ensure you are in the target range, and at this point you make the final head gasket selection to zero in on your target. There will always be some variation among the cylinders—typically a few tenths of a point. My recommendation is to grind the chambers of the highest computed compression ratio cylinders to reduce the variation to 0.1 maximum, especially if you are pushing the recommended SCR maximums.

In the case of this Special 300 HP-prototype engine, the final measurements yielded a range of 10.37 to 10.51 with the Keith Black KB157 (http://kb-silvolite.com/index2.php) cast hypereutectic pistons (0.5 cc dome, 1.678" compression height) and the 3830711 OE replacement .026" shim gasket. The head chambers had been previously relieved to eliminate bore overhang and the final volumes varied from 62.0 to 62.8 cc. It was merely a matter of a little more chamber grinding to remove about 0.2 cc to bring the two highest cylinders down to about 10.45, so the final CR spread is .08.

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