Compression Ratio How-to

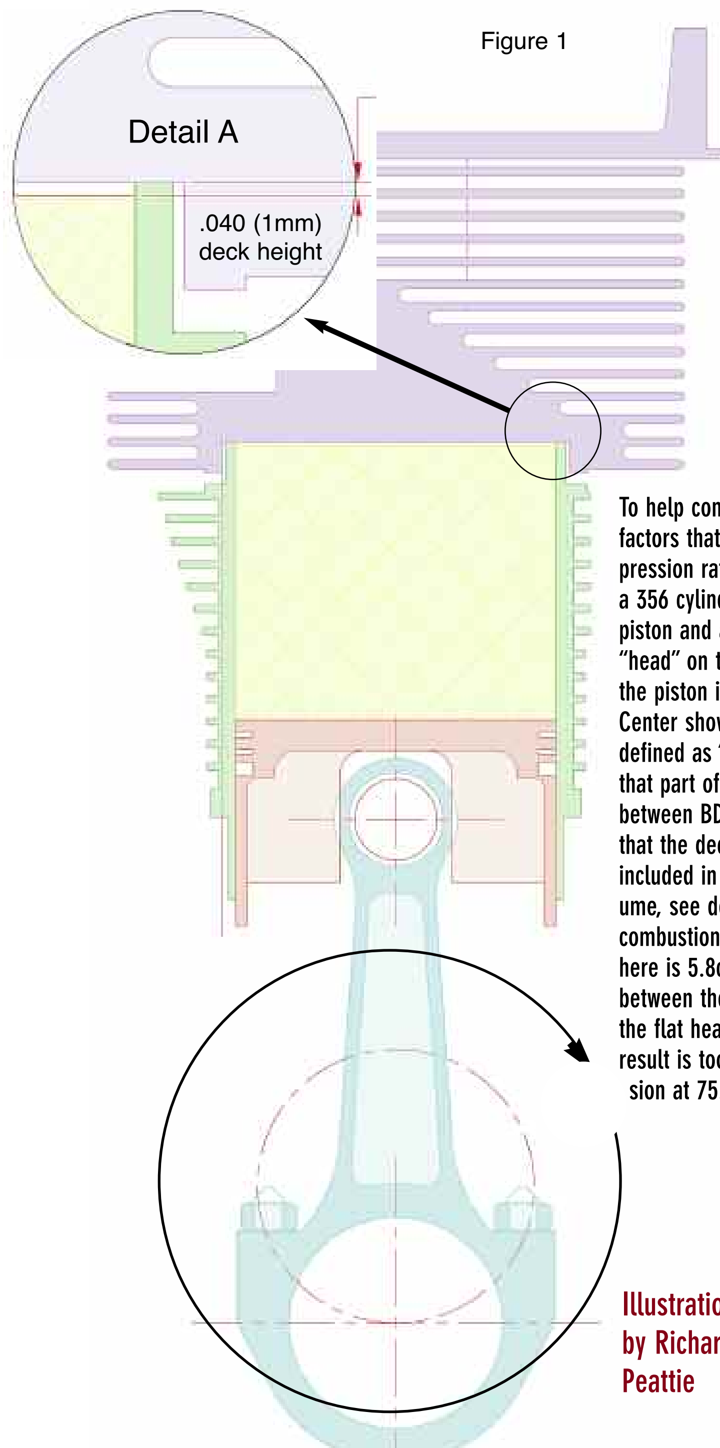
by Ron LaDow

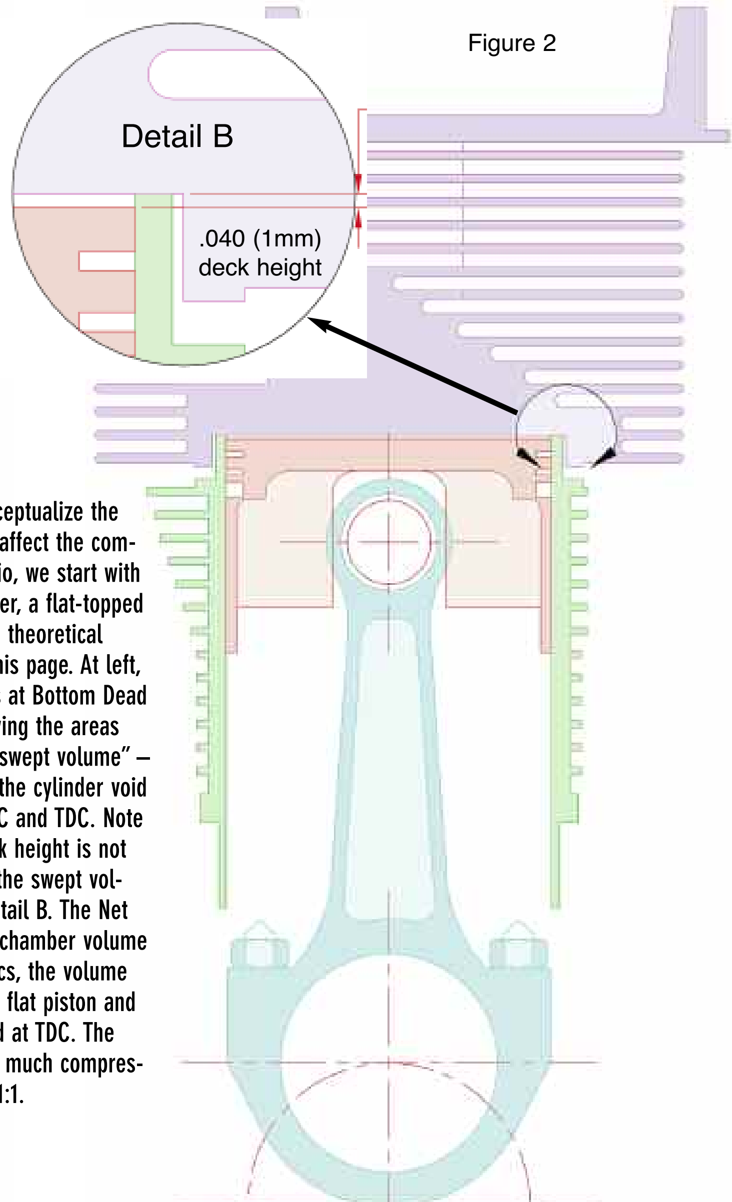
Explanation

As detailed earlier, we already know that setting compression ratio is basic to building a good engine, and 356s can run quite high compression ratios to good effect. We also found that an engine produces power as if all cylinders are at the compression ratio of the lowest single cylinder. To achieve a certain compression ratio, and thereby balance all cylinders to the same value, we need understand how it is found and how it can be altered.

To find the compression ratio of any cylinder, we measure two values; the "net chamber volume" and the "swept volume". Add both those numbers together and divide by "net chamber volume". That's the compression ratio of that cylinder. For example, one (the net chamber volume), plus nine (the swept volume), divided by one (the net chamber volume) equals 10:1 compression ratio or similar numbers. That's all there is to the final sums. These two terms ("swept" and "net" chamber volume) are very important in understanding compression ratio. They're not difficult to grasp and the terms will be used throughout the discussion. Other terms define portions of these values; they'll be introduced as needed.

Finding the swept volume is a snap; there are few available for 356s and all are known to accuracies far beyond what's required. They are all simply the bore area times the stroke.





To help conceptualize the factors that affect the compression ratio, we start with a 356 cylinder, a flat-topped piston and a theoretical "head" on this page. At left, the piston is at Bottom Dead Center showing the areas defined as "swept volume" – that part of the cylinder void between BDC and TDC. Note that the deck height is not included in the swept volume, see detail B. The Net combustion chamber volume here is 5.8ccs, the volume between the flat piston and the flat head at TDC. The result is too much compression at 75.1:1.

__Editor's note:__ We've discussed compression ratios several times before, but this particular approach to the subject, along with Richard Peattie's marvelous illustrations, provide an elegance that I hope will make this important subject that much easier for the home mechanic to grasp and put into practice, whether building his own engine or discussing options with an engine builder.

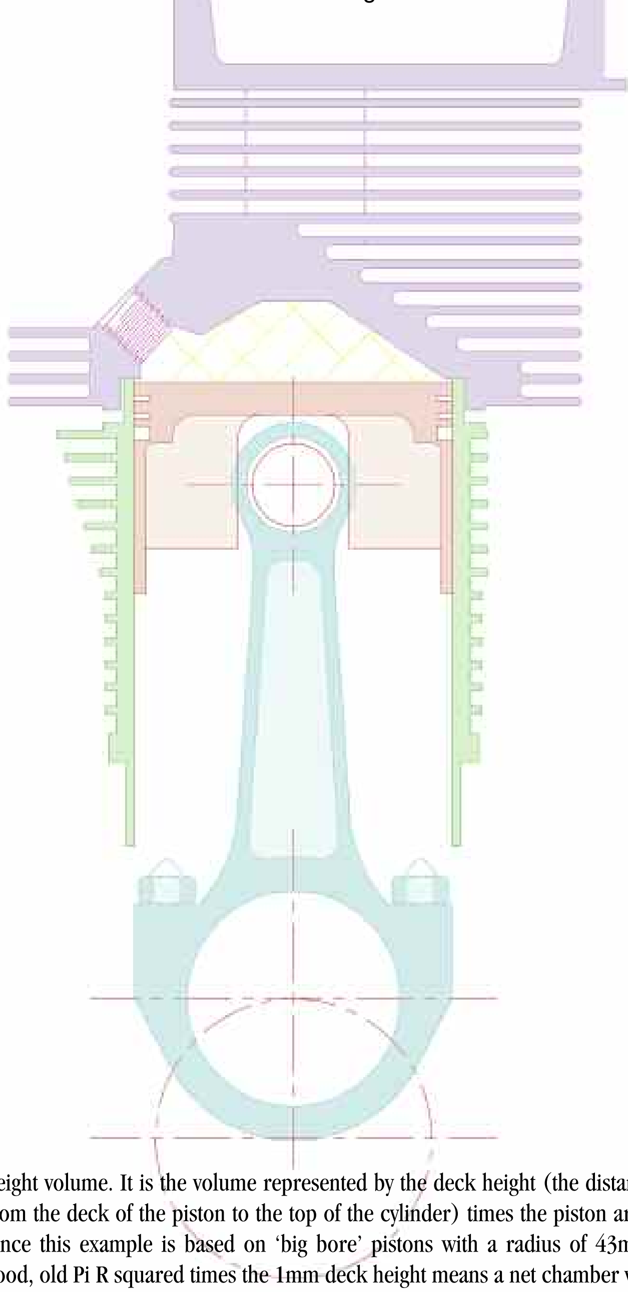
Illustrations by Richard Peattie

Finding the net chamber volume is where the fun begins. For reasons that are inherent in internal-combustion engine design, the head chamber (that's the part of the chamber that's in the head) and the piston dome (that's the lump on the piston tops) are irregular volumes and cannot be calculated. They must somehow be measured. To illustrate, we'll start with a chamber which is made of 'regular' forms that are easily summed; a flat head surface and a flat-top piston as in figures 1 and 2.

Fig. #1 shows the swept volume as the cross-hatched area in this simplified example. It is always easy to find; 'big-bore' (86mm) cylinders and a standard 74mm stroke yields 429.85ccs in swept volume. Note that the swept volume does not include the volume remaining above the piston at TDC (see details A and B).

Fig. #2 shows the net chamber in this simplified example; only the deck

Figure 3



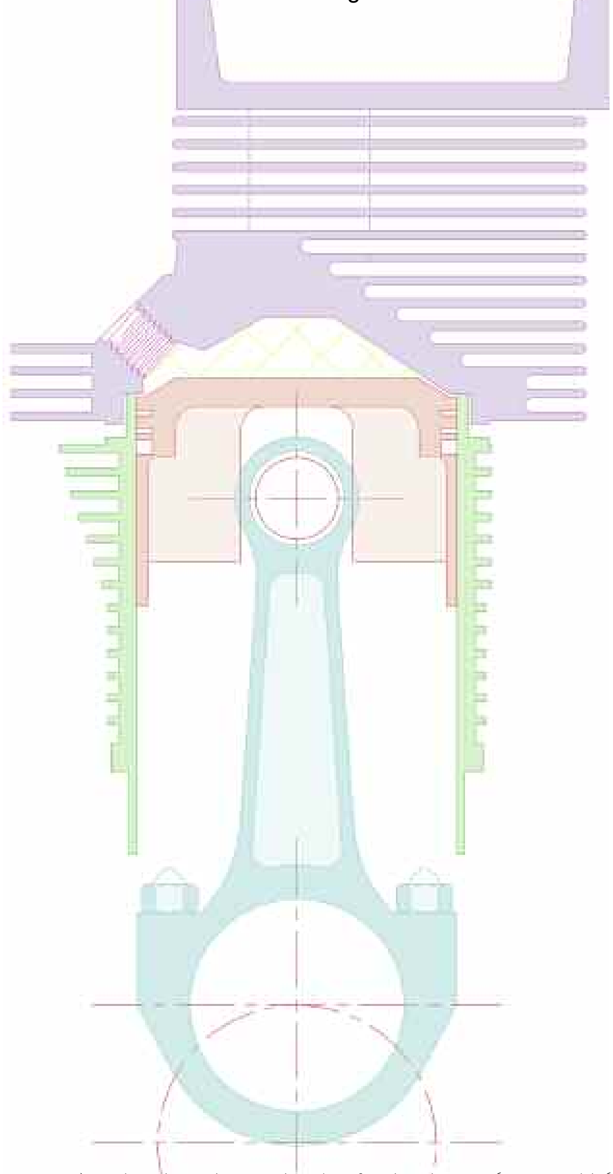
height volume. It is the volume represented by the deck height (the distance from the deck of the piston to the top of the cylinder) times the piston area. Since this example is based on 'big bore' pistons with a radius of 43mm, good, old Pi R squared times the 1mm deck height means a net chamber volume of 5.8cc.

Adding 5.8cc to 429.85 and dividing by 5.8cc says this cylinder has a 75.1:1 compression ratio. This is unrealistic, simply a result of the arbitrary design. As we get closer to real-world design, it'll change back and forth. Let's add the irregular head chamber:

Fig. #3 is a rough representation of a 356 head chamber on the same big-bore, flat-top piston as shown above. The deck height volume remains the same as the earlier illustration, but we've added an unknown volume in the head chamber. The only way to establish that volume is to measure it with a calibrated amount of liquid. I do not trust any markings on the heads unless I personally know and trust who measured and marked them and that I can verify that they have not been altered; any factory markings are by now untrustworthy. The tooling to measure them is not an extravagance for the hobbiest; alternatively some shops offer the service, but one way or the other, they must be measured.

For this discussion, we'll say that this head chamber measures 62ccs, since it is a common enough 356 value. Add 62ccs to the deck volume (per

Figure 4



above, 5.8cc) and we have the net chamber for this design: 67.8cc. Add 67.8 to 429.85 and divide by 67.8; a 7.34:1 compression ratio - good for kerosene. But most of our pistons have a dome as shown in Fig 4.

Now we've arrived at an archetype 356 net chamber. A piston dome rises above the deck of the piston and subtracts some volume from the net chamber and adds a bit more complication. The last example had a net chamber volume of 67.8; now we need to subtract the dome volume to find the new net chamber.

Ideally, you should measure the dome, but it takes some custom tooling to do so accurately. I do trust any and all of the cast big-bore pistons to have a dome between 17.1 and 18.0ccs but only because I continue to measure them. If that is close enough for your purposes, subtract 17.5cc (average dome) for a new net chamber of 50.3cc. Keeping the same 429.85 swept volume yields a compression ratio of, say, 9.6:1 (9.47:1 to 9.73:1)

As another example, two sets of Shasta forged pistons showed domes of 18.9cc, not a hint of change over the eight pistons. Subtracting 18.9cc (Shasta dome volume) from the earlier value yields a net chamber measuring 48.9cc and a compression ratio of 9.79:1 (48.9+429.85 = 478.75 / 48.9 = 9.79:1). This is approaching the limit of what can be used in a 356 on premium pump gasoline without going to twin ignition. With Shasta pistons you have data, with cast pistons you have some data and a choice. I have not yet measured the domes of pistons offered by others.

You can arbitrarily change either volume in this example. Do the arithmetic and see why we focus on the net chamber in changing compression ratios.

Review

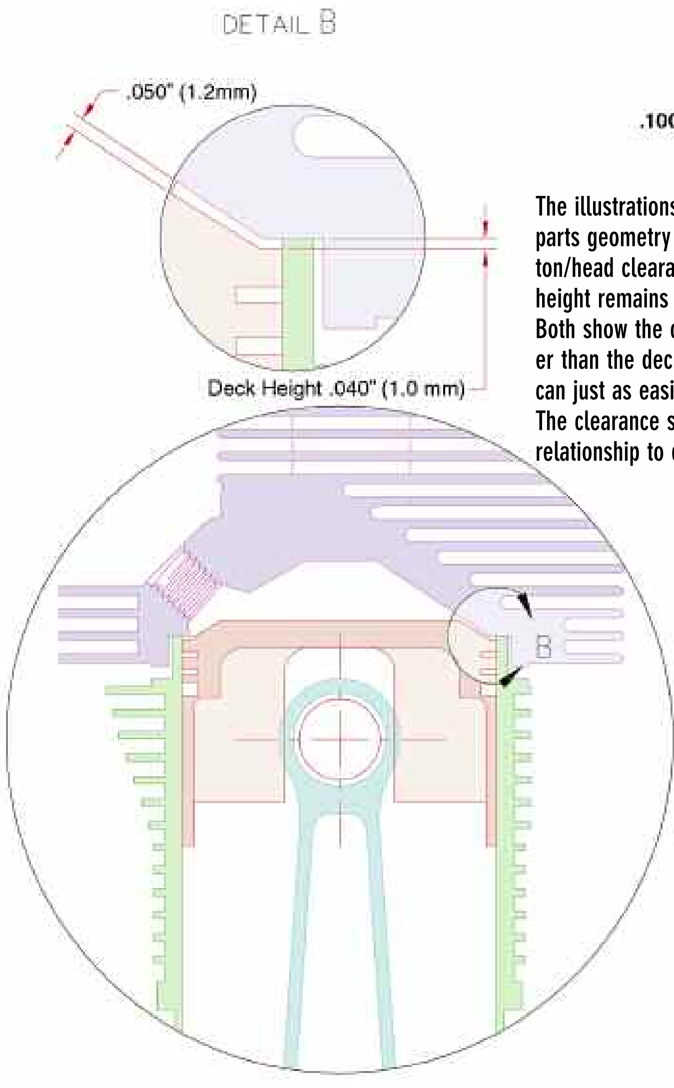
To repeat, the swept volume is known and fixed while the net chamber is unknown, highly variable and more important. The above examples show there are several measurements required and they vary in importance and difficulty. Here's a review of the values with some tips on techniques.

There is only one method of measuring the deck height: Measure from the top of the cylinder to the deck of the piston. It is not possible to measure it with clay or solder on the piston dome; see the illustrations and details below.

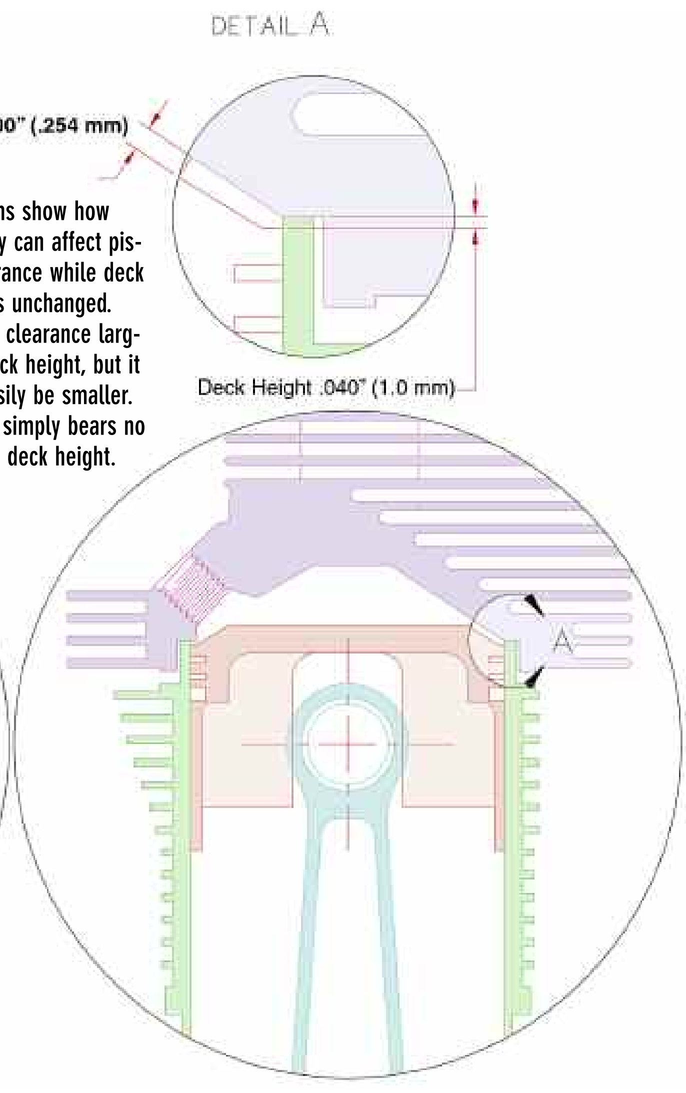
As you can see, the piston/head clearance can vary quite a bit while maintaining a constant deck height. Any clay or solder techniques will tell you piston/head clearance but will not yield any meaningful information about deck height. The 'trick' here (if there is one) is to measure above the ends of the piston pin (centerline in the illustrations below) to prevent funny data as the piston rocks in the bore. Good technique and a narrow tail on a dial caliper will tell the story.

The deck height is very important in establishing a compression ratio and is highly variable. It alone is determined by the consistency of at least five parts in each cylinder, any one of which may be out of specification. If you get funny measurements, they can be caused by errors in the compression height of the piston, the length of the connecting rod, cases which are no longer square, a crank which is not centered in the case or cylinders of varying heights. All of the parts can be checked by a competent shop, or tooling is available from Precision Matters and others. If your deck heights measure within .005", you're within .7cc in this particular volume; other volumes will vary also. .002" is not out of reach, but the choice (and the engine) is yours.

The 356 head chamber volume is important and not consistent. Head chambers have been accurately measured between 56.Xcc and 65.Xcc, a 9cc range, disregarding damaged heads. Measuring the chambers is not that difficult and the tools are available from Precision Matters and others. Alternatively, some shops will measure and record them for you. But visualization or caliper and rulers won't do it here; the volume must be measured.



The illustrations show how parts geometry can affect piston/head clearance while deck height remains unchanged. Both show the clearance larger than the deck height, but it can just as easily be smaller. The clearance simply bears no relationship to deck height.



Piston dome measurements are probably more difficult than any of the others. No one offers a tool to measure them (you are welcome to a drawing of a tool if you please), and tricks like positioning them at a certain depth in the bore and then filling the bore with fluid provide really bad data; you're better off guessing. The saving grace here is the consistency, especially in the forged pistons.

Confirmation

Commonly enough, the compression ratio is confirmed after a test assembly or the last assembly by bolting a head on the thing, placing the piston in question at TDC, arranging the engine so that plug hole is vertical, and filling the chamber with fluid. This presumably measures the final net chamber. It doesn't. The stock head chamber geometry in 356s is too complex to allow this method to 'burp' the cylinders such that there are no bubbles remaining. Testing shows two areas that will hold a bubble and suggests one or two more. Doing the hokey-pokey with the engine won't burp it either; gravity wins. There are, however, exceptions: Chamber geometry can be modified such that it will 'burp' completely. CNC-shaped chambers as offered by 356 Enterprises, John Wilhoit and maybe others should 'burp', but only qualified engine builders should re-shape a chamber to that extent.

Unless you have those parts, exactly how much the volumes are in error is unknown, as is the cylinder-to-cylinder error. The chambers are not only complex and inconsistent, but have often enough have been altered. I know many pro builders use this method, so it probably isn't horribly inaccurate. Plus, the actual compression ratio is always lower than is found so it is safe. How much do you want to pay your builder for the time to do otherwise?

As a result of my displeasure with this method, Precision Matters developed a tool set to measure this and other values; others may offer them also.

Alteration

Most often, it is not the low compression ratio cylinder that concerns us. Since it is the largest net chamber, it's the target, assuming it is within your desired range. That means the other three need to be altered to increase their net chambers until they match the big one.

The factory did not spec a net chamber tolerance, only a head chamber +/-.25cc tolerance. Do we presume they meant that as the net chamber? It takes a lot of work or a lot of luck to get all four net chambers within .5cc, so you have to choose the level of precision. That tolerance represents a spread between cylinders of say 8.85:1 and 9.0:1. It is possible to get them closer and it's much easier to get them 'way further apart. In the ranges under discussion, note that a .25mm (.010") base gasket represents a change of 1.45cc, from say 8.7:1 to 9.0:1.

This is also complicated by the 356 modular design; to maintain cylinder/head seal, any alterations must leave the tops of both cylinders on a single bank 'normal' to each other, so you can't just machine one cylinder shorter or add one base gasket to make up a difference in that cylinder. If you have a bank-to-bank difference, you can if you shorten both cylinders on the fat bank and shrink a couple. Or change the base gasket counts.

If you have measured all the parts, you have the luxury of "selecting". It is not uncommon that a 'big' cast piston dome will match up with a 'big' head chamber. You might have a couple of cylinders taller than the others and they might move. Piston compression heights (between the centerline of the pin and the deck) have varied; you can look there. Heaven forbid you have a long or short connecting rod, but if it works for you… Mix and match.

If you are using cast pistons, you can machine a bit off the top of the dome. I know some folks don't like this at all, but it's worked for me; .020" cuts and good longevity. The makers won't like this either, but you can get .0075" (~.25cc) off the tops of forged pistons if you need the last little bit. Obviously, the pistons must be weight-balanced after any cuts are taken. Racer motors will not tolerate either of these, and your risk tolerance is yours.

You can sink the valves deeper in the seats to gain some volume; but there are trade offs. Next, you can do a bit of judicious grinding in the head chambers. A Dremel tool is more than sufficient. Unless you have great experience, don't bother with any re-shaping of the chamber, just keep taking even material off the as-cast portions. About 2 minutes or so of even effort should show a gain of .5cc.

Finally, you can add or subtract cylinder base gaskets, but they must be done to both cylinders on one bank and both then gain or lose at least 1.45cc. If it works within your level of precision, then it works.

Summary

Compression ratio has a large effect on the function of 356 engines; higher ratios adding power, smoothness and economy. Factory engine builders had the luxury of a large selection of good quality parts for each engine but we don't. Since we have to work with what we've got, it takes effort to confidently achieve a specific compression ratio evenly across all four cylinders.

But the payoff is a fine-running, durable engine - an asset to any 356. None of the effort is beyond a dedicated hobbyist or a good pro shop; it's a decision you make.

Web Site Compression Calculator Tool

On the Registry web site under "Resources" (left column), then under "356 Technical Info", do a search for "Compression Ratio". You'll find a result entitled "Calculating compression ratios" which will bring you to two separate spreadsheets. Ron LaDow and Richard Peattie have each developed Excel spreadsheets with cells that will accept your particular measurements. Plug in numbers such as cylinder bore, head chamber volume, piston dome volume and the other data discussed in this article. Richard Peattie's version, below, already has an example of fairly standard data inserted as variables (green boxes). Ron LaDow's is similar but allows for calculations using the Precision Matters Tool.

Bore	86.00						
Stroke	74.00						
Engine cc	1719.41						
Volume per cylinder	429.85						
		#1&2 Spacer	#3&4 Spacer				
				1	2	3	4
Cylinder measured volume				64.50	64.60	63.20	63.60
Arbitrary Net Chamber				75.25	75.60	75.60	75.25
Measured Net Voulme				-10.75	-11.00	-12.40	-11.65
Spacer used		0.250	0.250	1.45	1.45	1.45	1.45
Net Raw Volume of Cylinders				-12.20	-12.45	-13.85	-13.10
Head Volume				55.80	55.80	56.00	56.80
Total Spacer Spacer Thickness		1.250	1.250	7.26	7.26	7.26	7.26
Spacer in inches		0.0492	0.0492				
Compression Ration to 1				9.45	9.49	9.70	9.44
Average Compression Ration	9.52						
Use this section when you are given the piston volumes and deck heights							
Note: Dome pistons have a negative value							
Deck height and Volume contribution		2.00	2.00	11.62	11.62	11.62	11.62
Piston Dome in cc's				-33.00	-33.00	-33.00	-33.00
Net Cylinder Volume Contribution				-21.38	-21.38	-21.38	-21.38
Head Volume				65.00	65.00	65.00	65.00
Total Spacer Spacer Thickness		1.25	1.25	7.26	7.26	7.26	7.26
Spacer in inches		0.0492	0.0492				
Bore	86.00						
Stroke	74.00						
Engine cc	1719.41						
Volume per cylinder	429.85						
Compression Ration to 1				9.45	9.45	9.45	9.45
Average Compression Ration	9.45						