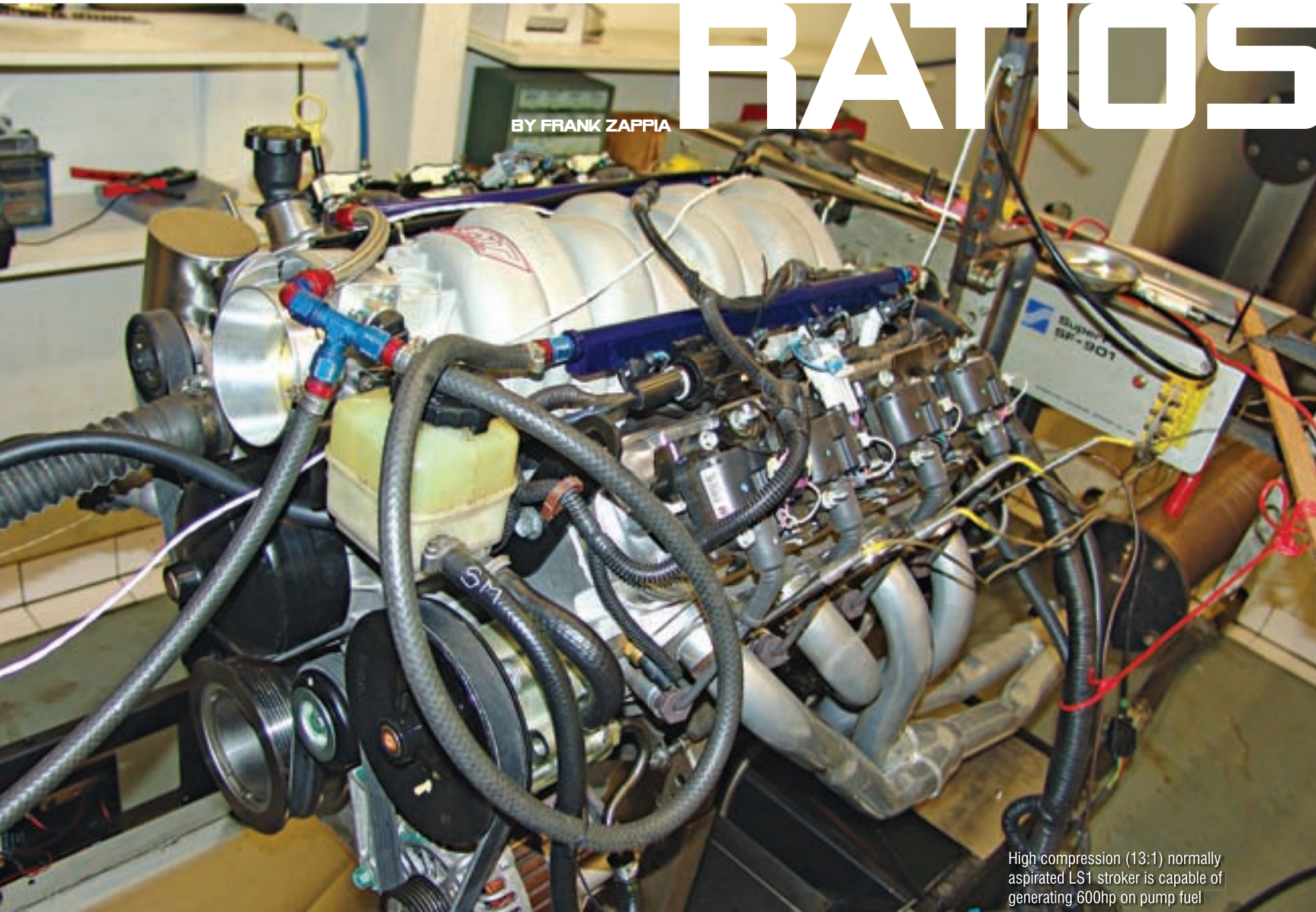


COMPRESSION RATIOS

BY FRANK ZAPPIA



High compression (13:1) normally aspirated LS1 stroker is capable of generating 600hp on pump fuel

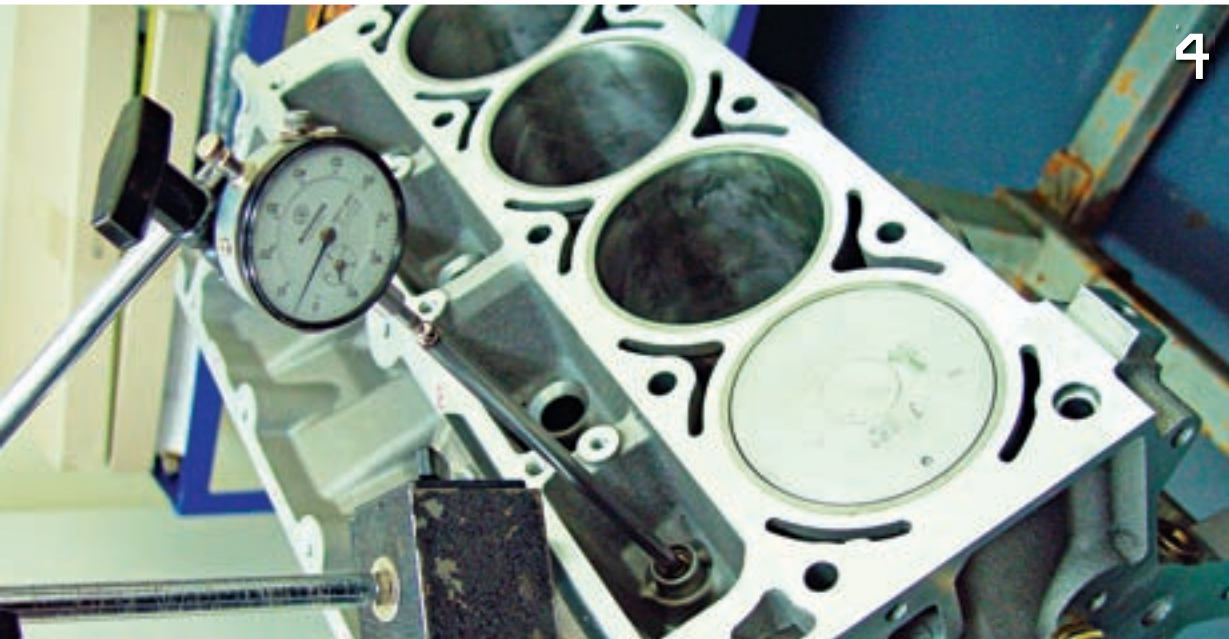
As any wise engine builder will know, there is no bigger contributor to overall engine tractability and performance than its internal compression ratio.

Determining power output, torque, fuel standard required and maximum boost level achievable, compression ratio is one of the most important choices that the engine builder faces when undertaking a high-performance build-up.

Like many other aspects of engine design and effect, though, the application of compression ratio has changed dramatically in the past decade with the advent of sophisticated engine management systems, making the seemingly impossible now a reality.

Big horsepower normally aspirated engines with big throttle-body arrangements and aggressive camshaft profiles can benefit from compression ratios as high as 12:1





COMPRESSION AND FORCED INDUCTION

Throwing in a curveball from left field is turbo and supercharging. These devices by virtue of their operation add charge density, and hence add compression to the cylinder.

The relationship of boost versus compression is represented as a straight line graph and needs to be taken into account when designing your performance engine.

Running the highest possible boost pressure with the lowest possible compression ratio is most advantageous purely from a power-production viewpoint. The thermal efficiency of the engine is at its highest level and cylinder filling at its greatest.

The reality, though, is that while quite powerful, engines built this way are low-compression slugs to drive at traffic speeds. They compromise basic driveability in the search for the biggest power figure and as such are fairly useless as a daily driver proposition.

The idea is to always keep the total compression of the engine, plus boost-added compression, down to below 14:1 if at all possible.

In a lot of cases, that means limiting total boost pressure (which is easy to do with a wastegate) and raising the static compression of the engine to get the desired result.



1) Stronger aftermarket conrods and forged pistons should be considered if raising the compression ratio of an engine much beyond standard

2) When using big positive-displacement-style superchargers, the compression needs to remain standard at minimum, or even be dropped slightly, to give the best results

3) Due to mechanical limits of the engines, the earlier 304/308 Holden engines need a lot more engineering work put into them to take the compression of a highly boosted combination than their later counterparts

4) Flat-top pistons as used in this LS1 engine are generally only used in normally aspirated applications, with a dished type giving greater clearance volume

5) The latest blend of ethanol pump fuels allow for higher-than-normal compression ratios due to their high performance knock-resistant nature

6) Two different cars, worlds apart, but the overall thread of compression versus boost equalling performance holds true regardless of engine type. Oh yeah, the black one was faster... much faster!



COMPRESSION RATIO - WHAT IS IT?

The best way of describing the compression ratio of any given engine always needs to be done mathematically, but to do this you need to understand some basic concepts, the most important of which are clearance volume and displacement volume.

It's these two measurements that are used to determine compression ratio, a number that tells us so much about how an engine will perform.

Clearance volume in all instances needs to be actively measured for any given engine. It can't simply be calculated due to the complex shapes found in modern cylinder heads and piston crowns.

Without actually going to the trouble of measuring an example engine, clearance volume can be described as the amount of volume left in the cylinder, plus the combustion chamber, when the piston is at the top of its stroke. For information on measuring this, please refer to the side-bar text.

Displacement volume, on the other hand, is the volume of the cylinder area travelled by the piston in a complete journey from top dead centre to bottom dead centre.

It can be calculated using simple mathematical equations such as the 'volume of a cylinder', but in the real world, this approach leaves a little to be desired by not taking into account the nuances of an individual engine.

Calculating the compression ratio with these two measurements then becomes quite simple, and can be expressed as:

Displacement Volume + Clearance Volume / Clearance Volume

The result expressed as a single figure is then put into a ratio form as XX:1 and reflects the true compression of the engine.

COMPRESSION INCREASING AND DECREASING

As a rule of thumb to the road user, the lower compression the engine, the slower and more lethargic it becomes. The less pressure is generated in the cylinder, the less dense the mixture and the less power is released.

Traditionally low-compression engines have less mechanical drag due to the lower cylinder pressures and hence tend to last a lot longer in service. It's not unusual then to see many of the 20-year-plus older engines, designed in an era when fuel was cheaper and of lower grade, to be low in their compression ratio.

High-compression engines, on the other hand, make more power for a given rev, fill the cylinder with a far denser charge and in most ways are far more efficient. High-compression engines generally excel in delivering low-RPM torque as maximum energy is extracted from every stroke.

As management systems have developed over the past few years and fuel efficiency is starting to become a key engine requirement, compression ratios have gradually crept up to previously unheard of (in production circles at least) numbers such as 11:1 and beyond. The LS2 engine is a great example of this.

PROBLEMS

You would think then that the logical choice would be to combine the highest compression ratio physically possible with the best tuning solution you could find, and hence make the most power.

You would be right, to a degree, but there are some very important considerations that the engine designer must keep in the forefront of their mind.

The most important is fuel quality. The higher the compression ratio, the more heat is released in the combustion process, the more cylinder pressure exists and hence the more knock-prone the engine becomes.

A way around this is by increasing the octane rating of the fuel to offset the increased detonation sensitivity of the engine. There are limits, though, particularly with street cars, as to the octane rating and quality of the fuel that is readily available.

Another, and less obvious, problem with high-compression engines is that of pure mechanical efficiency. As the cylinder pressure rises with increased compression, the pressure on the piston rings increases, and their drag in the bore rises dramatically – as does engine wear.

It is quite possible then for a compression point to be reached where the mechanical inefficiency of the engine counteracts the gains from the additional cylinder pressure.

It's this engine dependent theoretical point that top engine designers hover on the edge of, getting as close to as possible without actually stepping over. As a rule of thumb, the magical point is very close to 12:1.

Indicators that a compression ratio is too high are found in constantly blowing head gaskets and pistons with fractured ring-land area.

Talking to a couple of HQ-series racers who consistently ran compression ratios in the 13:1-plus region, they spoke of cylinder head gaskets that would literally blow out the side of the head while the engine was idling on initial warm-up.



RAISING COMPRESSION

There are many different ways of raising an engine's compression. The most practised is by simply shaving the cylinder head or installing a thinner head gasket.

This does nothing more than lower the clearance volume of the engine by reducing the size of the combustion chamber. It is the easiest way to raise the compression of an engine, and also the cheapest.

Another approach is to weld the cylinder head and change the squish/shape of the combustion chamber. It's more than simply adding some extra metal into the chamber, though, as there are some extremely complex design considerations to take into account here.

Chamber shapes are carefully engineered to promote swirl and even mixture burning, hence changing them is a job for the experienced engineer.

Changing rod length, or pin height, and moving the piston higher in the bore also works to increase compression, but you need to consider the cost and complexity of doing this, as it requires a total engine strip-down and rebuild.

The same effect can be generated with heavily domed pistons (or even reduced bowl if they are a 'negative shape').

Either way, or in fact any way, raising an engine's compression does fundamentally alter the way the combustion mixture burns and the way the flame front propagates across it. Alter at your own risk.

LOWERING COMPRESSION

The darling of the aftermarket industry is the thicker head gasket, used to increase clearance volume and in effect lower the compression ratio of the engine.

They are easy to fit but have plenty of drawbacks, such as increasing the surface area of the gasket exposed to cylinder pressure and potentially adding a detonation-inducing hot spot into the combustion process.

Most, though, are made from a highly metallic compound that can take the brunt of continual blasting, but you have been warned.

Shortening conrods and machining pistons are two other approaches that I am not particularly fond of when it comes to lowering compression ratio. Cut and shot conrods just don't work.

You also need to be careful when machining the top of the piston, as by doing this you weaken its base structure and its ability to handle increased thermal load.

Your best bet really is (much like raising the compression) to bite the bullet and buy some specifically engineered pistons for the job.

7) The same holds true for turbochargers, which are able to raise compression dramatically by adding boost pressure. Careful tuning is the key to engine survival with turbocharging and stock compression. The results, though, can be phenomenal

8) Reshaped combustion chambers like these ported with a CNC machine can reduce compression ratio for high-boost applications

9) Twin knock sensors seen mounted in the valley plate are the key to LS1 engines surviving in high compression and/or high-boosted applications

LIMITS

The raising and lowering of compression in various engines is purely dependent on the way the individual engine responds to this type of treatment.

Engines with extremely efficient cylinder heads such as the LS1 respond well to compression ratios in excess of 12.0:1 and make good power for the change.

Look back to an old-school 304, though, and find their inferior head clamping can introduce a whole new world of pain and blown gaskets if taking the same path.

Choice of management system also has an input into the equation, with detonation control being the primary characteristic aimed for.

While there is fundamentally nothing wrong with a well-jetted carburettor and re-graphed distributor, the set-up of these parts has to be exacting and carefully carried out to avoid engine-destroying detonation.

This is where the factory Holden Delco and Delphi management comes into its own, being able to retard the ignition timing and save the engine the moment detonation occurs.

With a normally aspirated engine designed to run on pump fuel, I would be hesitant then to use much more than 11.5–12:1 compression. With this static figure, you will have not only good response, but also the ability to control detonation with a high-quality management system.

Turbocharged engines for pump-fuel use shouldn't really exceed around 9.5–10.5:1. That's plenty when you consider the amount of compression increase from the addition of boost pressure.

With a good engine builder and a decent tuner, both of these N/A and turbo ratios should be achievable. Just don't let me hear of the old-school 'non engine management' approach of dumping in a massive spacer plate to lower compression ratio below 8.0:1.

If you need to do this, then you have done something wrong. Start again. *SC*



MEASURING COMPRESSION

There are plenty of ways you can measure the compression of an engine. Most tend to do it, though, when the engine is in bits and spend considerable time 'CC' checking the combustion chamber.

The process is simple. Close the valves fully and apply a flat glass plate to the surface of the combustion chamber with grease. In the glass plate will be a small hole, through which liquid can be inserted via a calibrated burette and the CC capacity of the chamber measured.

From there, the shape of the piston crown needs to be taken into account. One way of doing this is to push the piston an exact known distance down the bore, say 20mm, and then burette in enough solution to fill the cylinder completely.

Read the measurement and then subtract the volume of a 20mm-high cylinder from the reading. This will give you the CC of the piston shape.

You add whatever this is to the combustion chamber CC reading, which will be a subtraction (adding a negative number) if the piston is heavily domed or an addition if the piston is dished. This is your final clearance volume.

Displacement volume can be calculated by measuring the cylinder bore and the stroke, and then using the volume of a cylinder equation from there. For those that want to know, cylinder volume can be found in the following equation:

$$\text{Displacement Volume} = 3.141 \times \text{bore} \times \text{bore} \times \text{stroke}$$

4000

Plug those numbers into the initial equation quoted at the start of the text to determine compression ratio, and voila, there you have it, a calculated ratio.