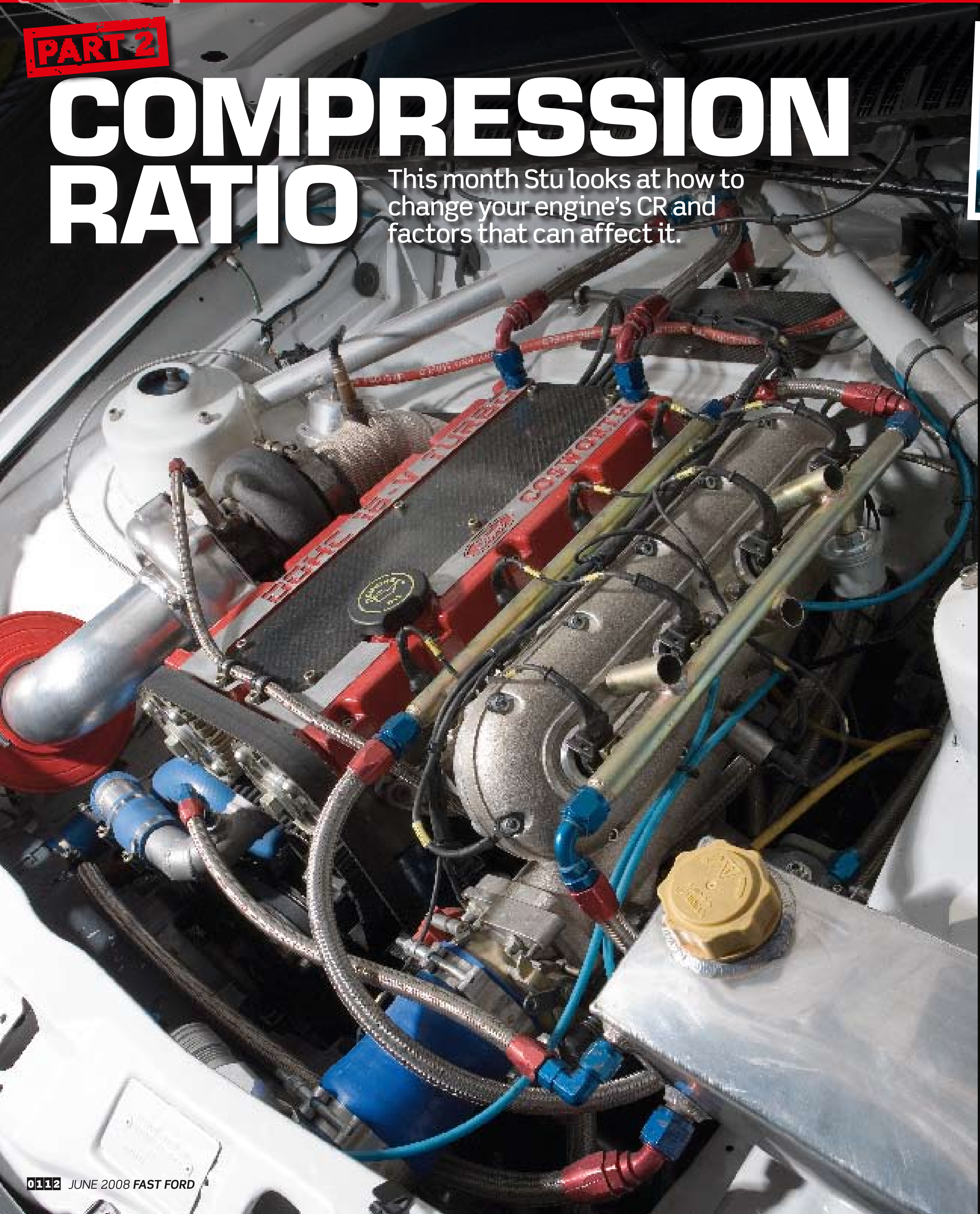
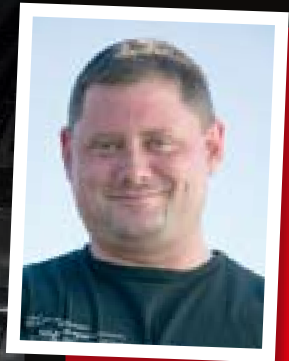


PART 2

COMPRESSION RATIO

This month Stu looks at how to change your engine's CR and factors that can affect it.



Having worked as a tuner for 17 years, Stewart 'Stu' Sanderson is one of the most-respected names in the business.

A Level 5-trained fuel-injection technician, in the past Stu has worked for a Ford Rallye Sport dealer, a well-known fuel-injection specialist and various tuning companies.

Then seven years ago he joined forces with Kenny Walker and opened up Motorsport Developments near Blackpool (01253 508400, www.remapping.co.uk), specialising in engine management live remapping, as well as developing a range of Evolution chips which are now sold all over the world.

He's also jointly responsible with Webmaster, Petrucci for www.passionford.com. Started in 2003, it's grown rapidly from a few friends contributing, to one of the biggest Ford communities on the web. His new forum, www.fordrsforums.co.uk, is also up and running.

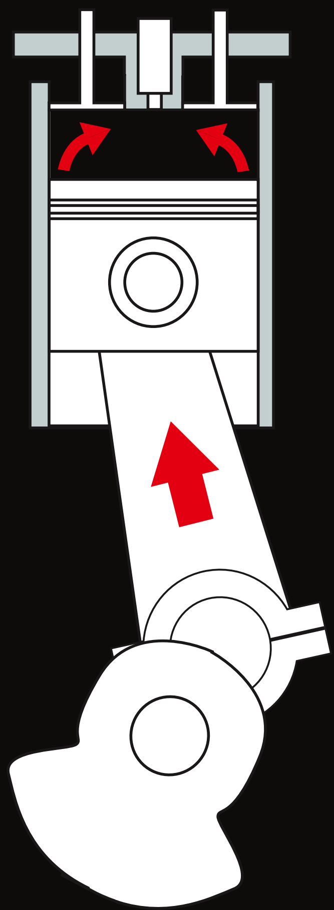
Stu's enviable knowledge of the workings of modern-day Ford performance engines means that every month he's just the man to explain how and why things work, and most importantly how they can be improved.

Hopefully you will have read last month's article on compression ratio and have fully grasped exactly what it is, what it means and how it is measured. This month I want to get a little more involved and discuss the merits of different compression ratios and why different engine geometries and specifications can steer us towards a compression ratio.

Static compression ratio is defined as the volume of the combustion chamber when the piston is at the very bottom of its travel (called bottom dead centre or BDC) divided by the volume of the combustion chamber when the piston is at the very top of its travel (called top dead centre or TDC).

CHANGE COMPRESSION RATIOS

An engine's compression ratio can be changed by either enlarging or decreasing the volume of the combustion chamber. This can be achieved in different ways but normally we would change the shape of the piston crown, add a thicker head gasket or remove some material from the piston crowns and/or the cylinder head.



THE 'SQUISH AREA' FORCES THE AIR/FUEL MIXTURE TOWARDS THE CENTRE OF THE COMBUSTION CHAMBER

Altering the shape of the piston crown is one of the most common ways of altering the compression ratio

SQUISH EFFECT

The most important thing when trying to change the compression ratio is to try and keep the designed squish area correct. The squish area exists between the piston's upper/outer edges and the cylinder head when the piston is positioned at exactly top dead centre. This section is designed to squeeze the mixture towards the centre of the combustion chamber as the piston reaches the top of its stroke. This creates a nice mixture swirl that distributes the fuel evenly throughout the combustion chamber and lessens the risk of pockets of fuel forming around the outer edges of the cylinder, which can lead to inefficiency and, in worst cases, detonation due to heat.

Squish effect is the main reason a decompression plate is accepted as the worst possible way to adjust the compression ratio. By its very nature it will increase the gap between the piston crown and the head, and decrease or totally eradicate the squish band, not to mention the extra sealing face it introduces (plate to block), which gives another area of potential compromise.

ALL IN A NAME

We have to look at the differences in compression ratio between a running engine and a stationary one. These two different measurements have slightly different names. A static engine's compression ratio is simply known as static compression ratio or just plain old compression ratio, and that's what we discussed in some depth last month. Once an engine is running, the measurement and terms which we use then all relate to the more complex 'dynamic compression ratio.'

Static compression ratio is one of the most important factors affecting how completely the air and fuel mixture is burned once it has been lit by the spark plug.

If you burn all of the air and fuel mixture then you generate more bhp. If there is some unburnt air and fuel left in the cylinder after the spark has been lit and the flame has started to propagate then you have not extracted all of the power available from the fuel and air that was introduced into the cylinder. You will also have a higher emissions output as a result of the incomplete burn. This completeness of burn is called the engine's thermodynamic efficiency and it is measured in units of energy called joules.

Volumetric and mechanical efficiencies are the other two main factors governing how much power an engine will make for any given level of fuel and air input. We may touch on those in another feature, but for now let's stick with the thermodynamic efficiency, as this is the one most closely linked with compression ratios. The relationship is not a linear one. If you were to double the compression ratio, you certainly wouldn't double the bhp output or even change the burn efficiency of the engine. A complex set of equations relate static compression ratio to the overall burn efficiency.

In general, the more compression we run, the better and more fuel efficient the engine will be, and the more throttle response the driver will enjoy. Conversely, the less compression we have, the less energy will be extracted from the fuel and the worse the fuel economy and driveability will be, although ultimately more power can be achieved when low compression is used with forced induction, as we will touch on later.

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Get it all wrong and this can be the result!

Alcohol/methanol fuelled engines, such as this Probe can run much higher comp ratios than their petrol counterparts

WHY NOT RUN A CR OF 30:1?

The problem is that as you increase compression ratio you also increase cylinder pressures and temperatures inside the combustion chamber. When air is squeezed hard inside a closed container like a cylinder, the pressure inside goes up further the harder you squeeze. As the pressure builds up, so does the temperature of both the mixture you're squeezing and the cylinder you are squeezing it in. (Think back to how hot a bicycle pump gets as you are nearing the correct inflation pressure on bike tyres. Now imagine thousands of psi being generated instead of just tens.)

These two simple factors can cause the air and fuel mix to ignite on its own without a spark from the plug. This is called pre-ignition because the ignition event happens prior (pre) to the spark plug firing. This can destroy an engine in seconds.

"Compression cannot actually begin until the cylinder is sealed and airtight."

There is a compression ratio level on every engine design that will cause pre-ignition and detonation on any given fuel type. The actual compression value varies with every engine design and depends largely on combustion chamber design. This can reduce detonation tendency significantly using methods such as low surface area to volume ratio combustion chambers, more squish area, more mixture swirl, better distribution of the air and fuel mixture into the chamber, and other factors such as the actual combustion chamber cooling ability of the engine design etc. All of these design factors reduce detonation risk significantly, and have an overall effect on the available compression ratio for that design of engine.

As you increase the static compression ratio, the cylinder pressures increase as well, this means that the piston must work harder to compress any given volume of air and fuel to this new higher pressure. This adds more power-robbing heat and friction to the engine and mixture, as well as massively increasing the engine's pumping losses as it is harder to compress the mixture the higher the compression goes. That takes away power that we have already developed from another cylinder and are using to drive the piston up on its compression stroke. There is no point gaining 5bhp per cylinder from extra compression on a power stroke, if it took 6bhp of your engine's power away to compress it that much further in the first place.

So, now you know that you can increase the power output of an engine by increasing its compression ratio, as this will normally improve the engine's efficiency. However, there are limits. In my opinion the highest overall static compression that cars in the UK should run on our pump fuel is around the 12.0 to 12.5:1 mark. There is also a point where we hit massively diminishing returns and this tends to be in the 14.0:1 area where we lose more through pumping losses than we gain through increased compression.

ALTERNATIVE FUELS EFFECT ON STATIC COMPRESSION RATIO

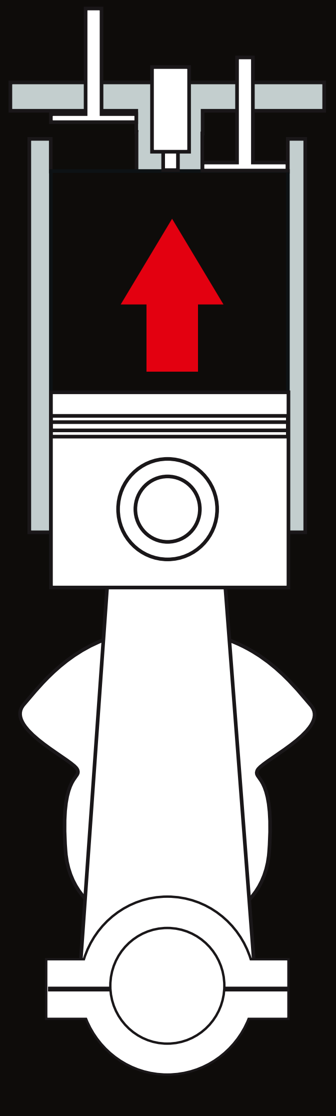
It is worth bearing in mind that alcohol-fuelled engines can afford to run higher compression ratios largely because the fuel used cools the engine's cylinders and burns cooler, thus massively reducing the risk of detonation. Methanol engines run massively different mixtures to petrol and methanol, and are another topic altogether.

DYNAMIC COMPRESSION RATIO

This brings me to dynamic compression ratio. To keep it as simple to understand as possible, the static compression ratio is the compression ratio we would get at starter motor speeds or when measured mathematically on a static engine. The dynamic compression ratio is the compression we get when the engine is actually operating and it is massively affected by the camshafts. It's fair to say that the camshafts' main job is to control the engine's dynamic compression ratio.

CAMSHAFTS AND DYNAMIC COMPRESSION RATIO

To understand the camshafts' role in an engine, you need to look at the engine's operation in depth and understand how your four-stroke Otto cycle engine works.



THE DYNAMIC COMPRESSION RATIO IS DEPENDENT ON CAMSHAFT CHARACTERISTICS

FAST FACT
An engine's compression ratio alters between when it's static and actually running

Let's look at the engine part way through its four-stroke cycle. The engine has completed its intake stroke and compression strokes, the power stroke has been completed and the piston is heading back up the bore. The intake valve is closed and the exhaust valve is open allowing us to expel the spent gases into the exhaust. As the piston rises, pushing the spent combustion gases out the exhaust port, the piston reaches top dead centre and reverses back down the bore. The exhaust valve now closes and the intake valve opens in its place. Fresh fuel and air are drawn into the cylinder through this open intake valve. The piston now reaches bottom dead centre and reverses direction so that it is heading back up the bore in order to compress the mixture... This is the critical point as far as understanding dynamic compression ratio, so if you are not with me fully, please go back to the start of this section and read again until it makes sense.

While the piston is at the very bottom, the intake valve is still open. As a result, when the piston is rising back up the bore, there is no compression actually occurring because of the open intake valve. Compression cannot actually begin until the cylinder is sealed and airtight when that intake valve closes. Once that intake valve closes, the air and fuel mixture starts to be compressed by the rising piston.

The ratio of the cylinder's volume at the time the intake valve actually closes will dictate the actual dynamic compression ratio, because the dynamic compression ratio is what the air and fuel mixture is actually subjected to in the real world.

It's all very well having a 500cc cylinder in your equation for static compression ratio, but try to visualise how pointless that static compression ratio calculation is to you when it is used on an engine with cams that don't close the intake valve completely until the piston is half way up the bore. If you did your static compression ratio measurements at this point in the cycle (half the stroke) you would have got 250cc and the compression ratio figure would have been *far* lower.

This example is exaggerated, but hopefully it will do the trick in helping you visualise that there is no actual compression when the piston is at bottom dead centre, or indeed for the first few millimetres of the bore, due to the intake cam still being open. So, the static compression ratio is always higher than the dynamic one at most operating points in a normally aspirated engine's operating cycle.

It is a truly complex subject and I have tried to explain it in layman's terms, but I accept it won't be clear to everyone and certainly doesn't apply to every engine in existence. I'm just giving you a good foundation to help you understand this complex subject.

"The camshafts' main job is to control the engine's dynamic compression ratio."

As the dynamic compression ratio is so affected by camshaft specifications, it is fair to say that cams can have as much of an effect on an engine's power band than the mechanical spec of the motor itself. An engine with mild cams may well need to be built to a lower static compression than one with wild cams as the wild cams' intake valve probably closes later in the compression stroke. This means that it will have less dynamic compression ratio than the mild cams engine that closes the intake valve sooner due to its lesser duration. Race engines are a great example of this phenomenon as they use really wild, peaky cams designed for high revs, and tend to have a late intake valve closing point in order to push power higher up the rev band and make maximum bhp.

When coupled with race fuel, such an engine can have a really high static compression ratio that you might think would detonate on the road. It's all down to the cams, the fuel octane and the expected power delivery band. When you add all these factors together it's not hard to see why it's common for someone to partially copy the spec of a race engine and then, not wanting to have a 10,000rpm screaming race motor, choose milder road cams. This ruins his high-compression ratio choice and he can't stop the engine pinking on pump fuel. The term 'a little knowledge is dangerous' has never been more apt than in situations like these.

Running on high octane fuel this massive power engine runs a 10:1 compression ratio

The compression ratio rules completely change when forced induction comes into the equation

FORCED INDUCTION

When we force induct an engine with a turbo or supercharger, we affect the dynamic compression significantly. Remember how we only had a potential 250cc of air in our 500cc cylinder when normally aspirated? Well, imagine if we now pumped that air in with a pump and compressed it at above atmospheric pressure so it couldn't escape while the piston was travelling back up the bore before the intake valve closed. Now we have a 500cc cylinder with potentially 500cc or more of slightly compressed air crammed into it, making our effective 500cc actually over 100 per cent efficient. (Meaning we have a volumetric efficiency of 100 per cent plus.) This has a massive effect on our engine's efficiency, and specifically, its dynamic compression ratio. So, now we have an engine that is extremely efficient and puts out great power and yet retains good economy due to the massive improvements in efficiency we have gained.

Can you see why manufacturers use turbochargers so much?

> "We can have a high static CR due to the fact we have quite a low dynamic one."

It is because of this massive rise in dynamic compression ratio that we have to often lower our static compression ratio in the first place, as we may now have a dynamic compression ratio that is too high for our intended fuel octane or mechanical strength. To lower it we need to make the combustion chamber bigger in relation to the bore capacity, so we squeeze the mixture a little less when compressing it on boost before we ignite it.

Of course, the more boost we run, the more air we force into the cylinder and the higher our dynamic compression ratio. In some cases, we can force more than 500cc of air into a 500cc cylinder by running so much boost the air in the cylinder is compressed before the valve even shuts. That's how we can get, for example, a power output of a 4-litre normally aspirated V8 out of a 2-litre, four-cylinder engine. We cram twice as much air into it by volume and run twice the dynamic compression ratio. (Oversimplified for explanation of course.)

HIGH COMPRESSION V LOW COMPRESSION

Any Internet forum user will have seen this question a million times, what's best for a turbo engine? High compression or low compression? Nobody has the answer because one tuner wants to do it X way and another Y. All that matters in a running engine is the dynamic compression ratio, not the static one. We can have a high static compression ratio due to the fact we have quite a low dynamic one. This is often the case on rally cars with restrictors fitted that stop the driver filling the cylinders with massive amounts of air. It is hard to say what is right because of all the other factors that come into play. The bottom line is generally the same.

We need to ensure the dynamic compression ratio does not cause any issues such as mechanical compromise of things like head gaskets, rods and piston crowns. We also need to ensure the cylinder pressures generated will not create excessive heat and that the engine's cooling system is adequate in the combustion chamber areas. Finally, we must ensure that once we can compress the fuel to this level and the engine can withstand the pressures and deal with the generated heat, we can manage the system to keep our exhaust gas temps at stable levels. This means the burn speed must be correct. Find out more about this next month.

NEXT MONTH

Different dynamic compression ratios and how an engine's basic geometry will affect the ratio you can run and why.

When you build a big power engine, getting the correct comp ratio is vital