THE EXPERT
STEWART SANDERSON

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, Stu has worked for a Ford Rallye Sport dealer, a well-known fuel-injection specialist and various tuning companies.

Eight 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 is the creator and administrator of www.passionford.com, which he started in 2003. It has grown rapidly from a few friends contributing, to one of the biggest Ford communities on the web.

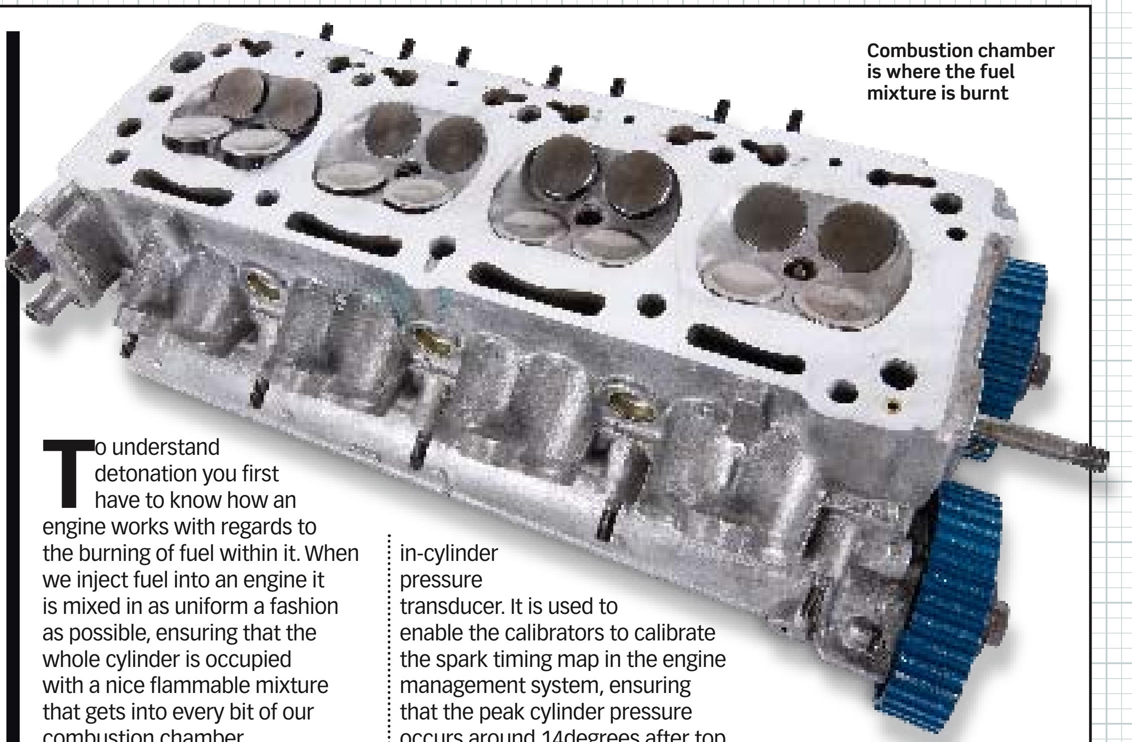
Stu's enviable knowledge of the workings of modern-day Ford performance engines means that every month he's just the man to explain how and why things work, and importantly how they can be improved.

TECH

DETONATION

PART 1

This month Stu gives us his big bang theories on detonation.



Combustion chamber is where the fuel mixture is burnt

To understand detonation you first have to know how an engine works with regards to the burning of fuel within it. When we inject fuel into an engine it is mixed in as uniform a fashion as possible, ensuring that the whole cylinder is occupied with a nice flammable mixture that gets into every bit of our combustion chamber.

When the piston gets near to the top of the bore, the spark is initiated via a spark plug. This ignites the mixture in the area between the spark plug electrodes and the burning fuel mixture's flame front begins to travel outwards in a uniform way, much like the ripples you'd expect to see when you throw a stone into a still pond.

The flame front moves outwards from the point of ignition and spreads evenly across the cylinder, ultimately quenching on the cylinder walls and piston crown when its energy has been expended. Ideally, the burn will be complete with no portion of fuel or air remaining unburned in the cylinder. It is extremely important to note that contrary to popular belief, at no point does anything 'explode'.

LOCATION LOCATION

One of the main factors a development engineer will look at when designing the engine is the location of peak cylinder pressure. This is measured using an in-cylinder pressure transducer. It is used to enable the calibrators to calibrate the spark timing map in the engine management system, ensuring that the peak cylinder pressure occurs around 14degrees after top dead centre (14deg ATDC), which is pretty much ideal on most engines, although anywhere from 12 to 18 is acceptable.

Depending on the chamber design and the burn rate of the fuel used we may have to initiate the burn by firing the spark at around 12degrees before top dead centre (12deg BTDC). Once initiated the burn would progress through the mixture and cylinder, finally making peak energy at 14degrees after the piston has peaked and started to fall, taking 26degrees of crankshaft rotation in all. The reason we fire the spark early is because it takes a finite measurable time to burn and reach maximum expansion.

Designers need to calibrate the system as above because a piston and rod can only travel so fast, and when it is at or near top dead centre there is no pushing it back down. The rod angle makes it very hard to move, so you need to ensure the peak push isn't too early, or you will waste energy trying to move an immovable object. If it's too late the piston may be well past its optimum position and you won't get to generate any push down on that stroke, losing masses of power.

There is a mechanical relationship between your spark initiation and your engine and neither one will work correctly unless the other is in the right place. The sequence of events must always be:

- Ingest fuel and air
- Close inlet valve then compress mixture of fuel and air with piston
- Initiate spark at correct point before piston gets to top
- Nice, smooth and progressive burn of fuel and air, reaching peak pressure in the cylinder when the crankshaft is at approximately 14degrees after top dead centre and heading back down the bore
- Nice, smooth release of energy from our fuel, which accelerates piston back down the bore
- A successful induction and ignition event

It's incredible to think that at 6000rpm this can

DETONATION V PRE-IGNITION

The two are related but distinctly different phenomena, and can induce distinctly different failure modes.

The main difference between detonation and pre-ignition is the fact that detonation always occurs after the spark has fired. Pre-ignition always occurs before the spark has fired.

Modern style coil-on-plug and coilpack ignition systems offer a more reliable spark

happen 50 times every second in each cylinder. That's 3000 times a minute!

WHAT IS DETONATION?

Detonation is the spontaneous combustion of the end gas (remaining fuel/air mixture) in the chamber. It always occurs after normal combustion is initiated by the spark plug.

In most cases, the initial combustion at the spark plug is followed by a normal combustion burn but for some reason, likely heat and pressure, the end gas in the chamber spontaneously combusts. The key point here is that detonation occurs after you have initiated the normal combustion with the spark plug.

When we initiate the burn of gas via the spark plug, the extreme cylinder temperature and pressure begin to increase substantially, understandably as it generates enough force on the crankshaft to move your car. If any of the conditions are not optimum we can have a situation where pockets of unburned gas spontaneously combust because they didn't have enough octane content to withstand the combination of heat and pressure. This is known as detonation.

Detonation is not always bad for an engine. A number of engines are designed to run with light levels of detonation almost permanently. Peak power is found right on the edge of detonation and many systems are tuned to monitor levels of it, and constantly evolve settings to keep them on the edge.

If you have ever driven a car that has too much spark advance you'll likely have heard detonation, or, what is known as pinking in the UK, (see boxout). It can run that way for thousands of miles and never cause any real damage. The higher the specific power output of the engine, the greater the sensitivity to detonation and also the greater the chances are of detonation causing terminal damage. When it is destructive, it can cause a range of damage, and can take months or only seconds.

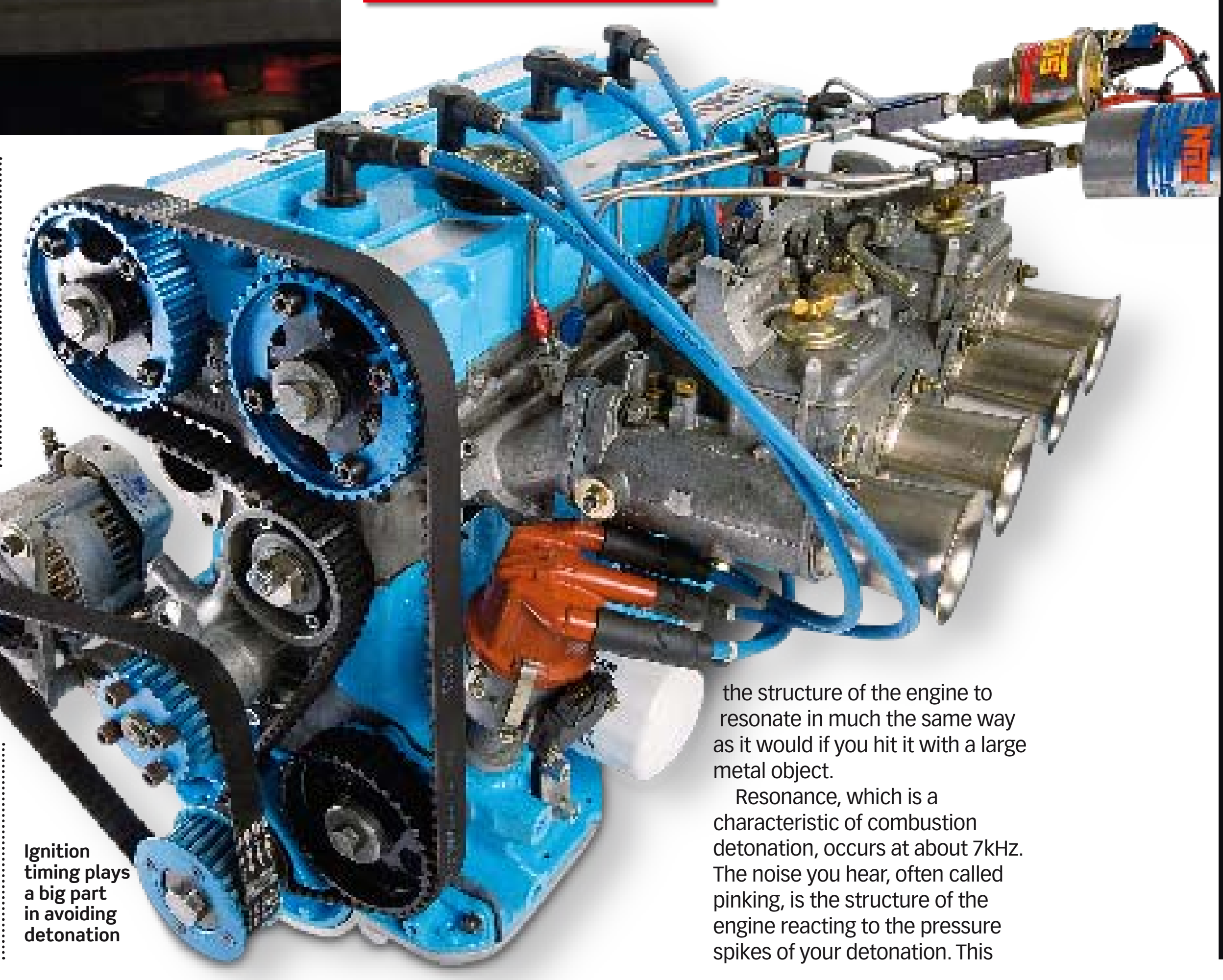
HOW DOES IT CAUSE DAMAGE?

When the fuel in our cylinders detonates it causes a very high and very sharp pressure spike in the combustion chamber. This pressure spike only occurs for a short time, but is deadly.

If you look at a pressure trace of the combustion chamber process, you would see the normal burn as a normal pressure rise, then all of a sudden you'd see a sharp spike when detonation occurred. That spike occurs after the spark plug fires. The sharp spike in pressure creates an extreme force in the combustion chamber that causes the structure of the engine to resonate in much the same way as it would if you hit it with a large metal object.

Resonance, which is a characteristic of combustion detonation, occurs at about 7kHz. The noise you hear, often called pinking, is the structure of the engine reacting to the pressure spikes of your detonation. This noise of detonation is commonly called knock and is another term used for detonation.

"DETONATION IS THE SPONTANEOUS COMBUSTION OF THE END GAS IN THE CHAMBER."



Ignition timing plays a big part in avoiding detonation

Some experts claim that the noise is caused by colliding flame fronts and it's a theory worth bearing in mind. Suffice to say there is a noise and it means open wallet surgery is looming!

This noise changes between engines and no two designs are quite the same when it comes to being able to audibly detect detonation. That's why manufacturers spend millions developing electronic systems to listen for engine knock on that particular engine installation.

DETONATION DAMAGE

The high impact nature of a detonation pressure spike can cause physical material failure. It can literally break the spark plug electrodes, break the porcelain on the spark plug and even cause failure of intake and exhaust valves! The piston ring land (between the piston rings), either top or second depending on the piston design, is also susceptible to fractures. Whenever I see a piston with a broken ring land, my immediate suspicion is detonation.

One of the most common telltales when inspecting an engine internally is a sandblasted appearance to the top of the piston. The outer edges of the pistons will normally have a sandblasted look after detonation occurs. Heavier detonation looks like small centre punch marks have been made in the alloy.

The mechanical pounding detonation causes will erode and fatigue material out of the piston itself. You can expect to see that sanded look in the part of the chamber most distant from the spark plug. You would ignite the flame front at the plug, it would travel across the chamber before it got to the farthest reaches of the chamber where the end gas spontaneously combusted.

It is common to see a piston that has scuffs on what we call the four corners. I know, pistons are always circular, however, when you look underneath a piston you'll see the gudgeon pin boss. If you look across each gudgeon pin boss it is usually made of a solid aluminium structure with no flexibility designed in. It doesn't need to have because the pin can expand directly out towards the cylinder walls. The skirt of the piston is very thin and flexible by comparison so when it gets hot it expands and deflects. When a piston soaks up a lot of heat it will normally expand in the skirt area and push the skirts into the cylinder walls, causing them to scuff badly on the four corners across the gudgeon pin boss. It's a dead giveaway of detonation.

The scuffed piston is often blamed on other factors and detonation is overlooked. It may be an indicator of a more serious problem, which may manifest itself next time with more serious results.

UNDER LOAD

Engines don't only detonate when under hard load. I'd say modern engines tend to detonate under light load more commonly, or at least under building load prior to full load being achieved.

An engine running at full throttle may be quite happy and safe due to a nice, rich air/fuel ratio at full throttle. However, its part throttle mixture may be much leaner and detonation may only be occurring at part throttle so the piston overheats and scuffs time and again without failure. The engine finally fails weeks, maybe months, later due to 'cumulative damage.' The guys examining the damage may rule out detonation because the failure didn't happen at full throttle with the engine flat out using max power. Detonation can occur at any time the engine is running.

Increased heat and pressures caused by detonation can cause serious damage to alloy pistons and heads

TYPES OF DAMAGE

Detonation generally causes three different types of damage, which can appear individually or all at once. All can ultimately lead to failure.

MECHANICAL DAMAGE:
Broken ring lands or holed pistons

ABRASION:
Pitting of the piston crown and ring lands

OVERHEATING:
Scuffed piston skirts due to excess heat input

The pressure spike is often so severe that it will cause the combustion chamber to rise to over 2000degrees. When you subject alloy pistons to this sort of temperature they start to melt, alloy cylinder heads can become soft and drop valve seats out. The list goes on...

Engines that are detonating will also tend to overheat. There is normally a boundary layer of gas in the cylinder that insulates the head and bore walls from the immense heat generated by combustion so we lose most of the heat into the exhaust.

During detonation events, the pressure rise is so great that the layer of gas is dispersed and heat is transferred into the cylinder head and bore walls. This causes the coolant temperature to rise greatly, causing engine overheating.

Unfortunately, this leads the engine into a loop of events that make things worse; the more it overheats the hotter the end gas and the more it wants to detonate, causing more overheating.

It's a snowball effect. An overheating engine wants to detonate and a detonating engine tends to overheat.

PINKING

Why do we call it such a ridiculous name? Well, the real term is "pinging" because it sounds like a metallic pinging noise, and that term has been used in the US for many years. I can only presume someone heard it and brought it back to the UK and translated it wrong. Great job that man!

NEXT MONTH

WHAT CAUSES DETONATION, HOW TO DETECT IT, HOW TO AVOID IT AND WHAT IS PRE-IGNITION.