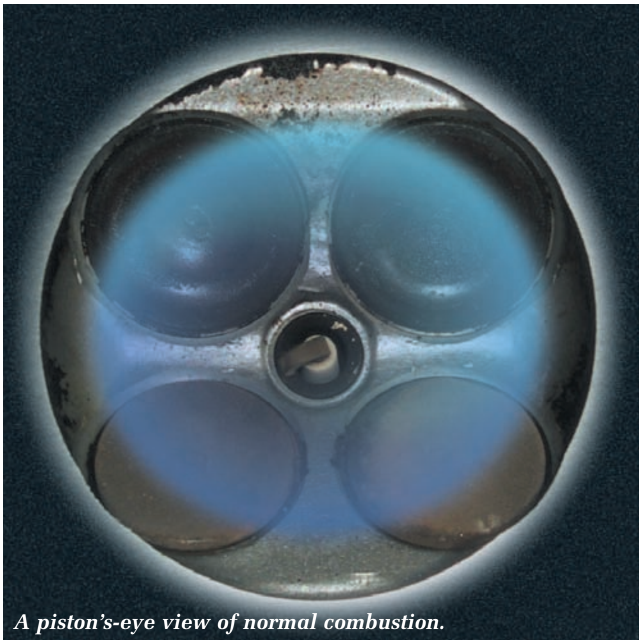
Blam!

Explosions Down Deep

Things that Go "Ping!" in the Engine


A piston's-eye view of normal combustion.


A piston's-eye view of detonation.

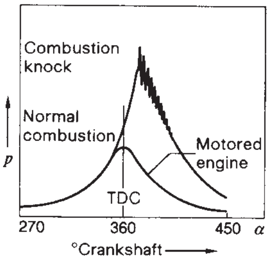
Some of the earliest cars had an odd, pivoting stalk on the steering column, right where most cars have the turn signal/headlight switch now. A few others had one on the dash. Serrations along a quadrant held the position you chose. It's a long-gone control – the spark advance lever, used to manually change the ignition timing from the driver's seat while underway.

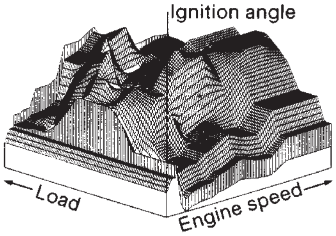
But who cares how those ancient cars worked, with their hand-throttles, cable-actuated brakes, drip-cup lubrication and carbide headlights you lit with a long wooden match? Can we really learn anything from mechanics who muttered oaths like "By gum and by cracky!"? Yes, and so can anybody who wants to understand how modern cars work, who wants to see how carmakers and mechanics of that time began the solutions to problems we're still solving.

Motorists in those old cars (like the Model T's in our photos) just had to learn what to do with the lever under different circumstances, because those were the days of *automatic-nothing*. For instance, they had to turn the lever to full-retarded before cranking the engine to get it to start. Cranking those engines, remember, really meant *cranking*, by hand. If you forgot to retard the spark lever, it was bad enough that the engine probably would not start, but the advanced spark and early combustion could also kick the crankshaft and handle backward and break your hand or thumb, too. Those were also the days of *'Safety?—What-safety?'* or at least *Safety-afterward.* Either a person learned to operate the controls properly, or the real world in the form of unintended physical consequences provided him an object lesson, with few prospects of much sympathy from the hardened onlookers of the time.


Spark Advance Lever

People learned to retard the spark to crank the engine to life, but also to advance it at steady cruise for more efficient operation and to retard it again when climbing hills, pulling a load or accelerating. Otherwise they lost power and burned buckets of fuel, or they toasted valves and punched holes in pistons. So when the Model T driver forgot, the sound of overadvanced timing, that characteristic bottle-clinking ping, readily audible through the Tin Lizzie's cast-iron block and head and its complete absence of acoustical baffling, reminded him or her to raise (retard) the timing advance lever.





Left: *Pressure Spike at Knock*
Below: *Spark Advance Map*

Then What?

But I don't know of a single car built in the last seventy-five years with a spark lever; that's all the business of the vacuum and centrifugal spark-advance mechanisms or the computer and knock sensor. So what do you do when you hear ping? Most modern drivers, of course, would either not recognize the sound at all or would blame it on 'bad gas' – which could be so, of course, along with several other likely causes. Bad gas now usually means gas with water or dirt in it, though. If it's your car or truck, you probably know to get off the throttle or change gears, to alter the combination of heat, load and engine speed producing the detonation. So what makes it happen and what kinds of damage would you expect to find on an engine you've taken apart for one or another failure after there has been detonation?

Varieties of Ping

More than low-octane fuel or mistimed ignition can cause detonation, but not every detonation results in that familiar, easily recognizable pinging sound, even though they're all related. *Detonation*, *preignition*, *knock* and *ping* all describe related cases of mistimed combustion, whether from ignition spark at the wrong advance angle or some other flame-trigger.

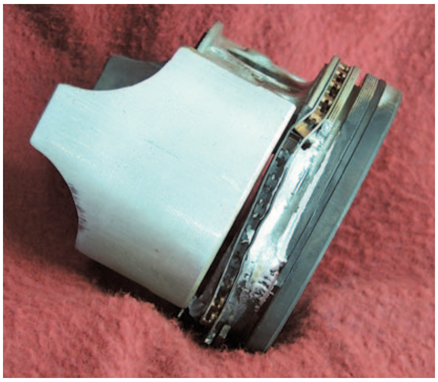
Some people use these terms with great precision, distinguishing carefully among several causes and several phenomena; other people use them almost interchangeably. I'll try to use them consistently here in what I take to be the most common patterns, but please understand you may hear them used differently by different people – words usually fit around their meanings more loosely than sockets fit over boltheads. Once you understand the combustion physics involved, of course, you can choose whichever terminology you like.

Whichever word for whichever phenomenon, they're all bad news for the engine producing them. That sound of hammering inside is just that – destructive hammer blows against the piston top and rings and against all the other surfaces of the combustion chamber. The detonation is equivalent to the force of ball-peen hammers striking the combustion chamber surfaces everywhere, beginning to flake the metal off. As you can see from the photo of the destroyed piston, pinging is not something you can ignore; it won't get better on its own; it *will* have bad consequences.

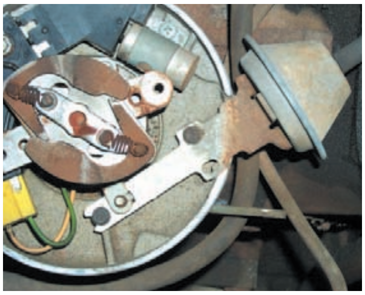
The problem arises in the first place because gasoline has a certain *ignition temperature* or *flashpoint*. This is the lowest combination of pressure and temperature at which a flammable liquid or vapor can or will burn. Octane numbers reflect a gasoline's flashpoint as well as its burn-speed. The speed of the fuel burn also corresponds to the peak temperature the combustion will reach and thus to the probability of creating oxides of nitrogen. We'll see in a moment how this connects measures to prevent detonation with measures to control exhaust emissions.

The lower the octane rating, the lower the flashpoint and the faster its burntime. We won't go into the different tests for octane here (nor into the foolishness of averaging them to get a 'pump octane number'). But the lower the fuel's octane, the higher the intake mixture's temperature and the higher the engine's effective compression, the more likely is knock. When you make knock go away by getting off the pedal, you're lowering both the intake mixture temperature and the effective compression.

Here's a quiz all of you former juvenile delinquents will pass easily (at least I do): As a kid, did you ever pry the bullet out of a cartridge, pour the powder out and touch a match to it? Sounds dangerous, no? Should explode in your face, ya dimwit turkey, right? But it doesn't. The gunpowder just goes *pffft!* It also makes a lot of acrid smoke, at least more than smokeless powder makes from the barrel of the gun with one shot. Evidently you don't get the right burn-speed without the right compression to keep the temperature up, the compression you find in the barrel of the gun. You find the same unexpectedly slow ignition if you pour a trail of gasoline on the ground and light one end (by the way, don't try this at home, either, kids!). Evidently the fuel-air burn in the cylinder works similarly to the gunpowder burn in the rifle barrel.



Detonation blew the rings through this piston's lands and grooves.



Vacuum Advance Diaphragm

Let's see how this works out in an engine's cylinders. The piston passes intake BDC, and the intake valve closes as the piston starts upward for the compression stroke. The temperature of the fuel/air mixture rises directly with the compression-stroke pressure increase, as much as several hundred degrees. Ordinarily, of course, the ignition system triggers a spark between the electrodes of the spark plug at just the right moment before the piston reaches the top of its travel, that just-right moment depending on engine speed, temperature and load. The spark sets the mixture in its vicinity burning, and the gas-blue fireball grows rapidly outward to fill the cylinder to within a couple thousandths of an inch of the relatively cooler combustion chamber walls (where the mixture stays below its flashpoint). The blue fireball should reach the chamber walls just as the piston reaches TDC.

That's what happens when everything works right, when the mixture and timing combine to produce a clean, gas-blue flame that starts with the spark, burns to the walls and consumes the last fuel about 50-55 degrees ATDC (of course, we still have the expanding hot gas continuing to work turning the crankshaft until the exhaust valve opens – it's not burning anymore, but it still has useful pressure).

When things don't, we have either misfire or detonation. Let's use the word *misfire* to mean any failed combustion event when the fire doesn't light, the combustion chamber stays dark and the fuel/air mixture just pumps out with the exhaust. That's not today's project, though. Let's use the word *detonation* to mean everything else but complete misfire or proper ignition and combustion. Detonation means the flame in the combustion chamber ranges in color from yellow to red, leaving behind carbon from the incomplete burn. Some of this carbon forms deposits in the combustion chamber, providing a start for hotspots and artificially raising the effective compression ratio (thus increasing the chances of more detonation later).

The fundamental combustion difference between a proper ignition and burn and each form of detonation is that the proper burn begins at the right time and from the plug electrode gap and grows across the combustion chamber gradually, though quickly. When there is detonation, of whatever kind, the fuel/air mixture suddenly ignites throughout the combustion chamber, exploding everywhere rather than burning in a controlled way. In a gun barrel, this is what happens if the projectile jams and the barrel bursts. This all-at-once explosion is also much less efficient in turning the chemical energy of the fuel into heat; thus the flame is orange or red because of the incomplete burn. The unburned carbon glows yellow to red from the heat. The incomplete burn also means carbon will deposit on the combustion chamber surfaces and in the exhaust system from the knock, and the high, but useless, pressure spikes before and just at TDC will begin whatever casting fatigue and other metal damage the detonation causes.

One common form of detonation, often called *preignition*, occurs because of a hotspot in the combustion chamber, either a carbon deposit or a metallic hotspot such as the tip of a spark plug of the wrong heat range for the vehicle's engine and current use or the hot edge of an imperfectly seating valve. Any hotspot works almost like another spark plug wired to a kind of prank ignition system, setting the fuel/air mixture aflame as soon as the combination of pressure and temperature reaches its flashpoint. This is hardly ever the right ignition timing position, so we have what amounts to excessively advanced ignition timing. Of course, if the hotspot isn't hot enough to light the mixture until *after* the spark plug does, there is no such problem.

Such carbon deposits can build from anything that results in a rich mixture, from a leaking injector to a driver who only takes short trips and never gets the engine warm enough to burn clean. After enough use, almost all engines grow carbon deposits, though gradual wear of the piston rings and valve sealing surfaces work in the opposite direction to reduce the effective, available compression. It remains true, however, that most engines need fuel of increased octane as they get older, contrary to everyone's initial supposition.

No doubt you recall seeing schematics in old car magazines showing the spark flamefront beginning to grow from the spark plug and another flamefront on the other side triggered by a hot spot. When the flamefronts collide, those old graphics would have it, they 'ping.' This explanation is, of course, nonsense. Flamefronts are combustion event-horizons, not physical objects; they aren't solid; they can't possibly collide. They're a kind of wave propagated through the combustible mixture, and like waves in every medium, they can easily interpenetrate one another without any effect. Plunk a couple of rocks at either end of a pond, watch and listen – you'll hear no clang of waves. Dual ignition systems, for engines with two spark plugs in each cylinder, have worked on piston-engined aircraft for many years without any such problem.

Then what does cause that knock when there's a hotspot? The same thing that causes it when you have overadvanced timing or excessive compression for the octane of the fuel (from either the gas or from milling too much metal from a head during valve work, not to mention the effects of retarding the valve timing).

In normal combustion, the burn proceeds across the combustion chamber at just below the speed of sound (which increases with pressure and temperature, however). Once the burn approaches the speed of sound for the prevailing combustion chamber conditions, this flags the approach of the threshold of knock, of the thermal-pressure point at which the *remaining* fuel-air mixture will just spontaneously burst into flame everywhere. Under those circumstances, however, the burn is not as effective at oxidizing all the fuel. Fuel does not mix perfectly with air. Even the most current of swirl-chamber designs merely aims at creating enough turbulence to mix the nonhomogeneity as evenly as possible.

Fuel burns efficiently only in those microlocations, those mixture pockets, where it stands in the right proportion to the admixed air. In a normal burn, the progress of the burn itself microturbulates the mixture as it flames across the chamber. When temperature-pressure conditions cross the detonation threshold, only the first and most spontaneously ignitable pockets of the fuel-air mixture burn. The other places, admixed throughout, are then so deprived of either fuel or air they don't burn completely, and the residual fuel, roasted to carbon black by the heat and partial combustion, either blows out the pipe or starts coating the exhaust surfaces.

Just because the combustion is incomplete, however, does not mean the pressure built is lower. Since the burn is nearly all at once, the pressure buildup is also nearly instantaneous, spiking chamber pressure right at TDC, where it does no work whatever and just hammers against the metal surfaces. This is, in fact, the source of the pinging sound – the engine block and cylinder head respond to the pressure-blow just as they would to a hammer blow, by ringing at their natural accoustical frequency.

That characteristic frequency provides the key to the measures used to correct ping on computer-controlled engines. There are two general strategies: first the use of recirculated exhaust gas through the EGR system to dilute the fuel air mixture enough to effectively slow the rate of burn that detonation is less likely, and second, spark retard.

Slowing a combustion burn with exhaust is sort of like slowing or even putting out a fire by burying it under ashes, of course, but that would work, too. The main purpose of the EGR system, however, is to reduce the maximum temperature of the combustion burn to prevent the formation of oxides of nitrogen and their effect on the vehicle's emissions. A side effect of slowing the burn (and thus lowering the burn-temperature) is to reduce the chance of spontaneous ignition for the yet unburned part of the intake mixture. Ordinarily, an EGR-failure induced detonation will not go away with any measures taken to retard the spark (see the next few paragraphs) because the inert-exhaust-poor mixture is then so detonation-prone no spark is needed to ignite it anyway, just as if the engine were dieseling!


Knock Sensor

Regular ignition spark can produce knock, however, if the spark is too advanced for the combination of engine speed, load and temperature. Carmakers try to set up the ignition system in such a way as to reduce this chance to a minimum, but good power and good fuel economy require the spark advance almost always be at its maximum to achieve the most work from each cylinder's fuel-air charge. So most carmakers set their systems to keep the spark advance right at the edge of knock under most running conditions (except for deceleration and idle). Besides that, ignition timing has a profound effect on exhaust emissions: When there's knock, *everything* bad in the exhaust increases, the major reason emissions standards have made spark timing nonadjustable.

The chief device to allow as much ignition advance as possible, considering that fuel octane will vary with the supplier, the place and the time of year, is the knock sensor. While several different types are used, the most common is the piezoelectric knock sensor. Piezoelectric sensors produce a signal voltage only when the crystal inside them sustains slight stresses from the G-forces of vibration. By choosing just the right crystal dimension and material, a system designer can make a knock sensor respond to the engine's characteristic ringing frequency when knock occurs, but not to other vibrations. When the knock sensor generates that voltage signal, the computer can then ratchet the ignition timing back for the affected cylinder until the knock goes away. Most modern cars can retard timing by the individual cylinders, but earlier engine control systems retarded all cylinders together.

So, let's hope we've persuaded you. Whatever you call it, knock, ping, preignition or detonation, it's bad for an engine and will have destructive consequences. Causes and cures are things you understand. ■

— By Joe Woods

Credits: Thanks to Snyder's Antique Autos in New Springfield, Ohio, for letting me shoot the beautiful old Model T's in their showroom. Ditto to the Ford Motor Company for the antique car they brought to Oshkosh.