DETONATION AND

Knowing the signs and avoiding trouble

I recently had a email from an operator who reported engine damage and that he suspected the octane quality of the fuel he had been using. The damage can be seen in the accompanying photographs.

The principle damage can be seen to be an area of pitting in the cylinder head between the spark plug hole and the valve seats. The operator suspected either pre-ignition or detonation was the cause of the damage. Pre-ignition and detonation are totally different phenomena; pre-ignition occurs when there are hot spot deposits within the combustion space to act as an ignition source, whereas detonation is the spontaneous auto ignition of the unburned end gas through an increase in its thermal energy.

DETONATION

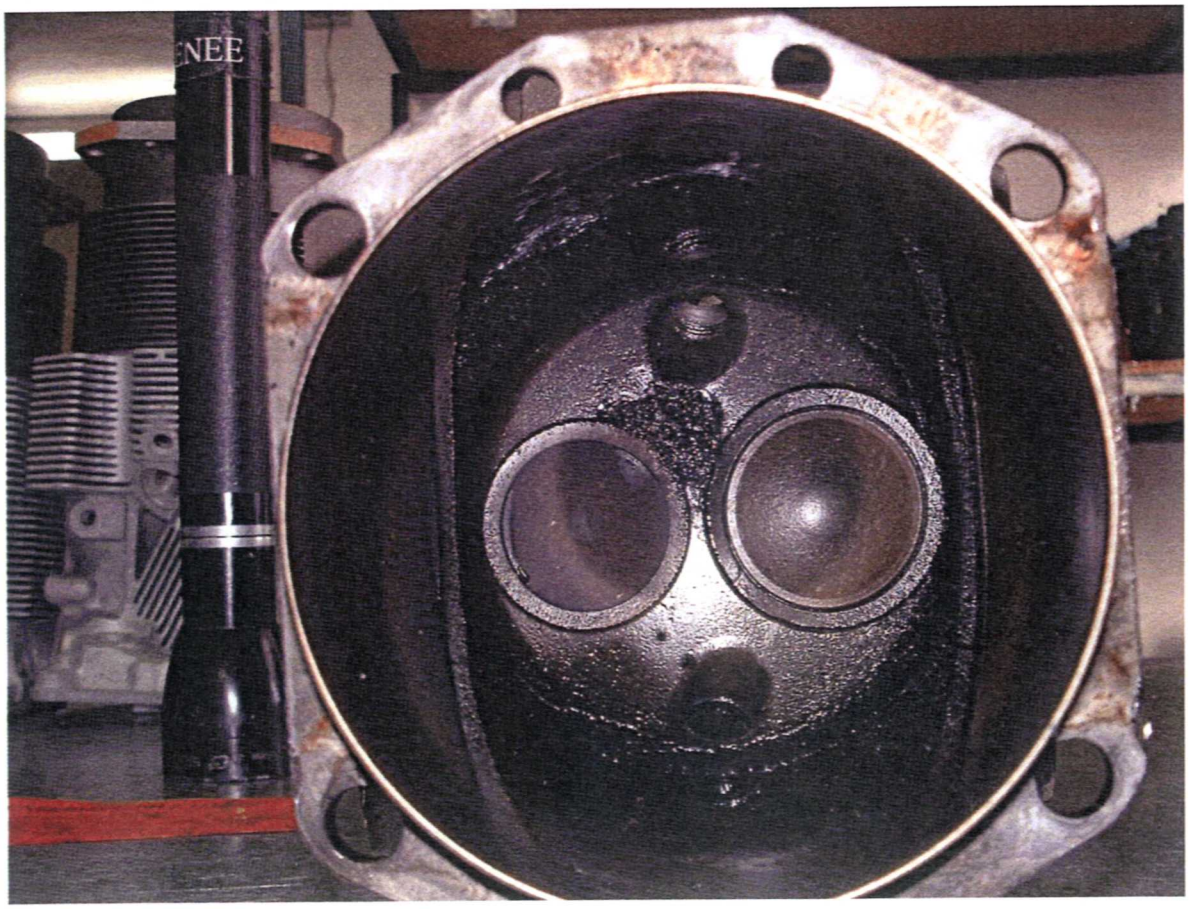
In this case there are none of the characteristics of detonation damage here and it should be ruled out as a cause.

Detonation damage tends to manifest itself around the circumference of the piston, as this is where the unburned end gas is. By the very nature of detonation, it is the end gas is where the problem first starts and it is where the damage is typically seen. As detonation is caused by the progression of the flame, and the expansion of the gas behind the flame putting energy into the unburned air/fuel mix, then damage is typically not found in the area where the flame first starts. Damage around the spark plug is not characteristic of detonation.

PRE-IGNITION

Now this is more probable, with the spark plug being a source. If, for some reason, the spark plug is running hot, then it could itself present a source of ignition prior to the spark and result in the damage shown.

The area that appears to be damaged most in these photographs is the area between the spark plug and exhaust port. This is where the cylinder head runs hottest, as it is difficult to cool this area (lack of metal to conduct heat away,



PRE-IGNITION

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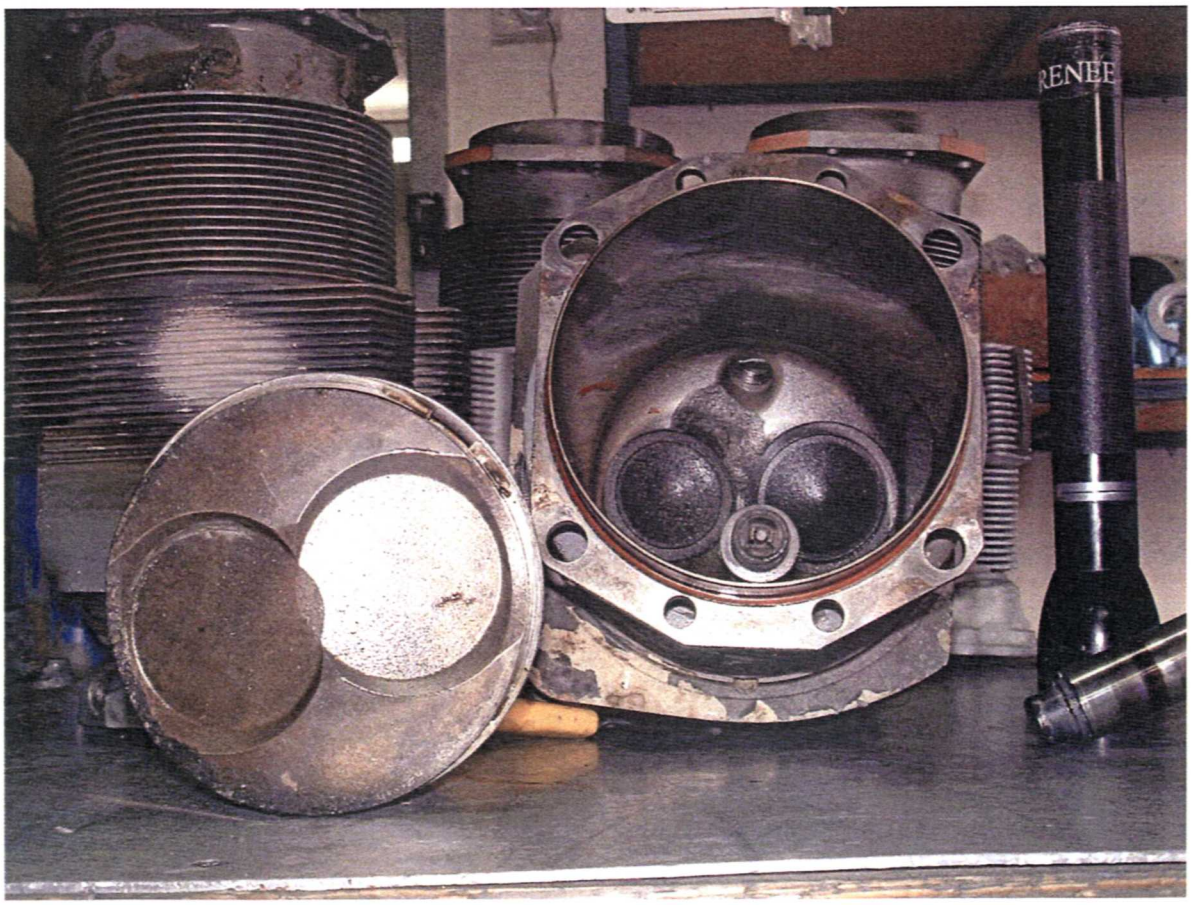
poor cooling fin area around that area and the exhaust port is perpetually dealing with hot gas). Cylinder head cracking is common in this area in engines which are cooled too rapidly because of the poor thermal path from this area, and it is common to see weld repairs between the exhaust port and one of the spark plug holes as a result. So we know that this area runs hot and this further supports the pre-ignition supposition.

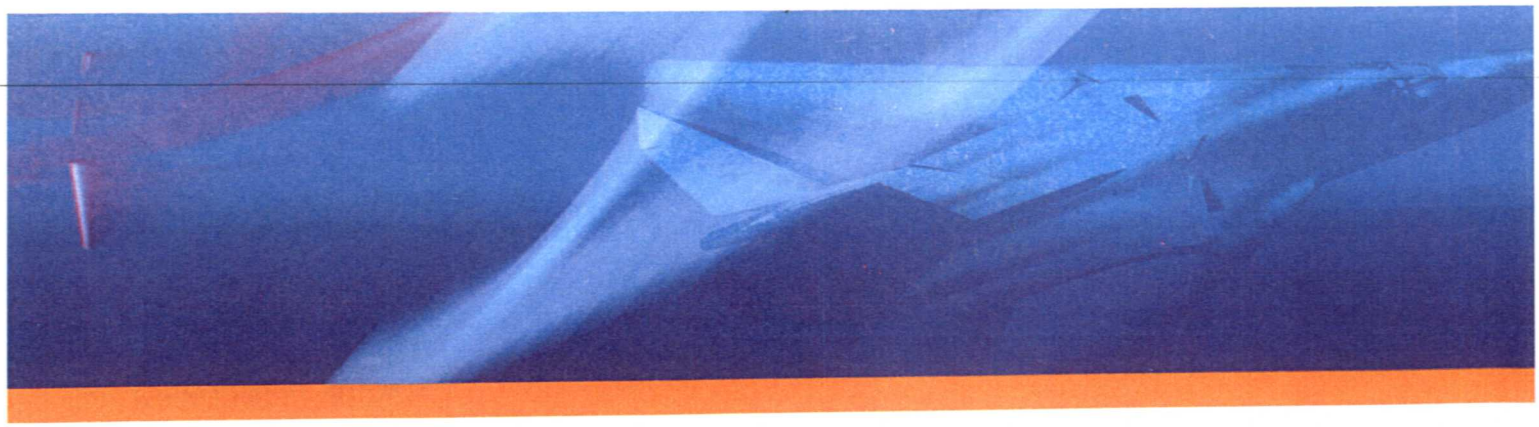
The next question is why might the spark plug running excessively hot? In this case the spark plug insulation was damaged, offering one of two failure mechanisms. Firstly, the plug insulation might have been the primary failure, presenting a hot centre electrode, which could then have caused the secondary pre-ignition damage. Alternatively the plug itself may have run too hot, creating a pre-ignition source, which damaged the cylinder head and subsequently shattered the plug insulation.

It is known that using a plug with too high a heat rating can cause pre-ignition, but the plugs used in this case were ones recommended by Champion, and the plug type was the coolest plug rating offered for this engine. The next factor that can make an engine run too hot is excessive leaning of the fuel mixture.

Leaning increases combustion temperatures and there are a few recommended practices to help stop this from causing a problem. First of all, leaning should not be performed at any altitude at power settings above 75% power as this threatens the risk of detonation; however, the reduction in air density above 6,000 feet generally means that a normally aspirated engine cannot make more than 75% above this altitude and so leaning is generally possible at all throttle settings above 6,000 feet in normally aspirated engines.

I have seen a lot of people leaning to peak EGT and beyond, but I much prefer to see pilots lean only to 50 oF on the rich side of peak for reasons that I will not cover here, but perhaps is an area that we can cover in a future edition of Tech Talk. This is particularly significant if operating above 65% power without specialised engine instrumentation. Also of note, when leaning an engine, is that the cylinder head temperature (CHT) is actually a more important marker than EGT, even though this temperature lags the EGT by some margin. If the CHT's are redlined then the mixture should be enriched to cool the head,





regardless of what the EGT is saying.

Finally, are the spark plugs torqued up correctly with a new copper washer each time they are replaced? Most pilots are unaware that the majority of the heat transfer from a plug is through the gasket and seal area and so a good thermal contact in these areas is essential. Too often do you see copper washers being re-used when changing spark plugs, without a thought to either replacement or at least annealing the old washers to soften them. Used, hard washers result in a poor thermal contact and can lead to spark plugs overheating and pre-ignition damage within the engine.

If the temperature management of the engine is adequate and the spark plugs were suitable and fitted properly, then this implies that the plug damage may have occurred first, but why?

PLUG DAMAGE

Of course, one obvious way of damaging a spark plug is through mishandling before it even reaches the engine. If you do ever drop a spark plug, particularly onto a hard surface such as the floor, you should always replace it, even if there are no obvious signs of cracking on the insulator. Spark plugs can easily be damaged and it is far better to replace a plug than risk catastrophic engine damage due to failure of the plug insulation after assembly.

Another common cause of plug damage is through rapid cycling of the engine temperature - power off descents after cruise, or excessive leaning, which rapidly increases exhaust gas temperature (EGT), are typical scenarios. As we have covered before, Lycoming recommend that the rate of change of cylinder head temperature should not exceed 50 oF per minute. However, the problem of spark plug insulation failure is more often associated with rapid heating rather than cooling.

Rapid heating of the insulator nose causes it to run hot. The bore of the insulator runs cool due to the proximity of the centre electrode. The temperature differential sets up tensile stress within the insulator and can cause failure if the strength of the insulator is exceeded.
It is also possible that deposits between the electrode and the insulator can increase the heat transfer between the electrode and insulator bore and so the bore temperature further lags behind the insulator nose temperature, making the problem worse, so dirty plugs can aggravate the problem.

So one possibility is that the engine was running hot, and / or underwent rapid temperature cycling. Another possibility is that the spark plugs were damaged prior to fitting. Were the plugs being cleaned properly with the correct media (glass beads or Aluminium oxide powder)? If not then damage during cleaning could introduce cracks, which result in spark plug insulation failure within the engine.

SUMMARY

In this example the evidence does not support detonation as being the cause of the damage. This is not a problem that manifests itself around spark plugs - in fact the spark plugs are the one area that detonation cannot be the problem as detonation happens ahead of the flame front and needs a flame propagation to occur. Therefore, in this case, the octane quality of the fuel is not a contributing factor.

However, the damage is consistent with pre-ignition with the spark plug as the ignition source. The central questions that would need answers to take the investigation further are why the plug is either a) running too hot, or b) what is causing the insulation to fail?
Once using the correct grade of spark plug, evidence that the plug is running too hot implies that the engine itself is running too hot (high CHT and EGT), or there is a poor thermal contact between the plug and head. Alternatively it could be that there is poor cooling of the cylinder head caused by poorly fitting baffles for example.
If the primary failure was with the spark plug insulation then this implies that there was either rapid heating / cooling cycles in the cylinder (perhaps combined with plug deposits), or that the plugs were damaged when they were inserted.

I have used this example as a way of highlighting common causes of pre-ignition damage that perhaps gives some food for thought and some simple preventative measures that you can take when considering the operation of your own aircraft.

HAPPY FLYING.

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