A Review of Champion Spark Plug Insulator Cracking Issues In TCM Engines

Synopsis

Tornado Alley Turbo, Inc.(TATI) has published Mandatory Service Bulletins[1] (MSB) requiring replacement of Champion RHB32S fine wire spark plugs in their STC'd turbo-normalized installations. The reason for the replacement is given as cracks in the spark plug insulator tip causing pre-ignition leading to severe engine damage. The evidence given in the TATI MSB's was examined and compared to published data on piston and spark plug damage. It was found that the issue is not likely to be due to fine wire spark plug insulator cracking but to operation of the engines in detonation. It is detonation that led to the severe engine damage and incidentally to spark plug insulator cracking. Based on the evidence given in the MSB's it is likely that the cause of the detonation was operation of the engines for some period of time in TATI's "red zone".

Discussion

Tornado Alley Turbo, Inc.(TATI) has published Mandatory Service Bulletins (MSB) requiring replacement of Champion RHB32S fine wire spark plugs (with massive electrode plugs or other manufacturers' fine wire plugs) in their STC'd turbo-normalized installations. The reason for the replacement is given as cracks in the spark plug insulator tip causing pre-ignition leading to severe engine damage. The Service Bulletins say that cracked RHB32S insulators have been found in naturally aspirated engines too. The MSB's have illustrations of a naturally aspirated SR22 damaged piston, cracked insulator and a graph from the aircraft engine management system. Given that the MSB is for TATI turbo-normalized engines and TATI claims to have examined numerous engine data downloads, it is curious that they chose to include naturally aspirated damage photos and data download for their turbo-normalized MSB.

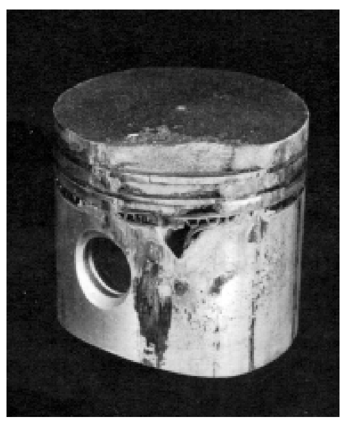
The MSB also states that the "modest initial operating CHT precludes... detonation". Although abnormally high cylinder head temperatures reduce detonation margins, low cylinder head temperatures do not preclude detonation. It is true that "cracked and damaged" spark plug insulators can cause pre-ignition, it is probably not accurate to say as the MSB's do that they are a "common cause". Other causes of pre-ignition are combustion chamber deposits, mis-installed helicoils, sharp edges left in manufacture, installation damage and incorrect ignition timing. Although the MSB does not specifically say that the engines of the two incidents and one accident had damaged cylinders and also had cracked insulators, this is the implication. Assuming this is true then it is possible (but in my view, unlikely) that the cracked insulators caused damaging pre-ignition. It is well known that detonation can crack spark plug insulators and the spark plug may be among the first victims in a chain of damaging events. Champion RHB32S fine wire spark plugs have been in service across a wide range of applications from modest to high powers with very little trouble history until the TATI Lean of Peak procedures have come into wider use. Is it possible that later Champion RHB32S spark plugs have a manufacturing defect? The possibility is there but it is not consistent with the evidence.

[1] TAT SB11-01 through SB11-07

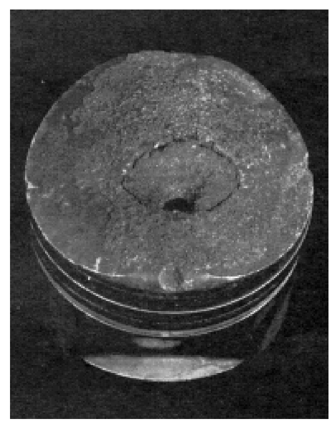
The German company Mahle (one of the world's leading producers of engine components including pistons) has an excellent book titled Piston Damage - Causes and Remedies. This publication discusses the causes of pre-ignition and knocking and gives photos of the damage caused by each. The Mahle book recognizes that an incorrect heat range can cause pre-ignition that results in "local overheating of the piston material and fusing of the crown." Also stated is "The spark plug can also be damaged due to knocking combustion and can then likewise trigger pre-ignitions... Causes for knocking combustion with resulting pre-ignition are spark advance, too lean fuel air mixture *(my underline)*, a defective injection equipment or low-octane fuel".

The photo evidence in the MSBs are much more indicative of detonation than pre-ignition. The photographs in the MSBs show a piston that has a pock marked crown, broken ring lands and a scuffed skirt. This is what one would expect from detonation damage; pre-ignition would result in a hole melted in the piston and little scuffing or land damage. Below are photos from TATI, Hastings (a well known piston ring maker) and from the Mahle piston damage book. Although it can be difficult at times to discern the difference in detonation and pre-ignition damage because each can occur or cause the other, it is clear from the photo's that the TATI piston is largely detonation damage. The TATI piston shows the pocked crown that is illustrated by Mahle Figure 3.7-1 and scuffed skirt characteristic of detonation damage that is shown in Mahle Figure 1-3. There is little resemblance between the TATI photo and Hastings and Mahle Pre-Ignition Damage photos.

Piston photo from TATI SB11-05

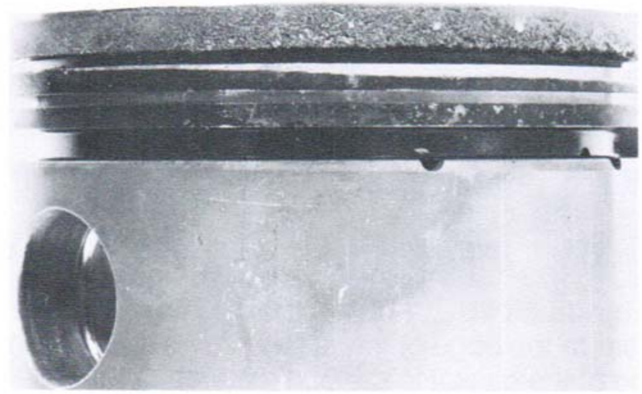


Detonation Damage (Hastings)

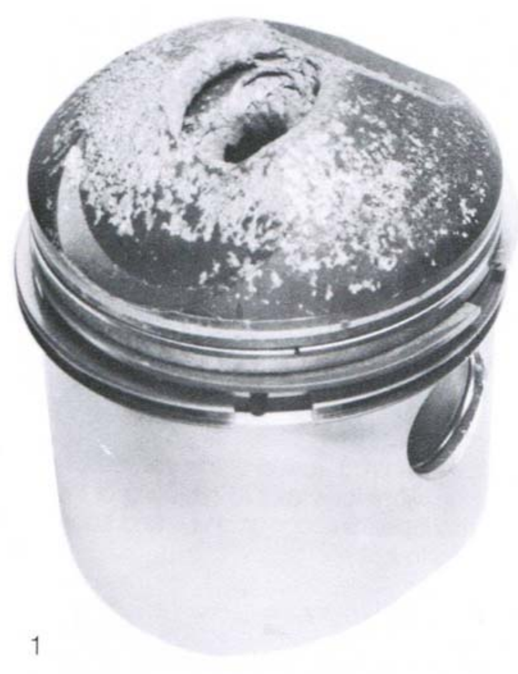


Pre-ignition Damage (Hastings)

Mahle Fig 1-3 Detonation Damage

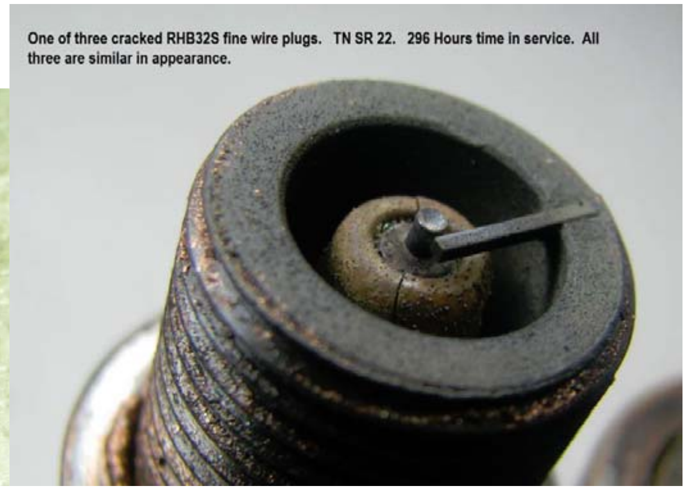


Mahle Fig 3.7-1 Detonation Damage



Mahle Figure 3.1-1 Pre-ignition Damage

The spark plugs in the MSB photographs also show the characteristics expected from detonation damage, that is; broken insulators. Pre ignition damaged plugs will have the center and ground electrode melted.



Photos from TATI SB11-05, photo on the left is from a naturally aspirated SR22 and the one on the right is from a turbo-normalized SR22.

Photos of damaged automotive spark plugs, left plug is detonation, right plug is pre-ignition damage. (photo's from Champion)

Another source of information on cracked spark plug insulators is Sacramento Sky Ranch's website. The photo below and the diagnosis of what caused the crack are from http://www.sacskyranch.com/eng72.htm .

Cracked aircraft spark plug insulator (electrode insulator)

1. Thermal shock from pre-ignition or water ingestion (float planes).
2. Mishandling and cleaning.
3. Detonation.

The illustration below is from Champions AV6-R Aviation Service Manual. The fine wire plug on the left has a cracked insulator much like the MSB photo of the turbo-normalized plug. The Service Manual description of the fine wire crack attributes the crack to either improper maintenance or detonation. It is unlikely that the spate of cracked insulators is due to improper maintenance and more likely due to detonation.

Cracked Core Nose

Normal engine operation cycles thermal shock to the core nose, and insulator materials and designs are chosen to avoid core nose cracks from such thermal shock. However, occasional abnormal engine operation will exceed even the built-in safety factors, resulting in infrequent core nose cracking.

The typical cracked core nose condition shown may be caused by improper cleaning or gapping procedures and by detonation. These conditions are discussed in detail elsewhere in this manual.

Fine Wire Electrode

Massive Electrode

In various blogs, George Braley of TATI is careful to say that the cause of the insulator cracks has not been determined but the implication is that the spark plugs themselves are defective. The RHB32S spark plug is Champions highest volume fine wire spark plug and it has been widely used over many years in many different airplane engines including GTSIO520s and TSIO 520/550s operating at higher power than the engines in the TATI Service Bulletins. Until recently, cracking of the insulator has been almost non-existent. Champion fine wire plugs have been used in high output racing aircraft engines for many years without insulator breakage. There is little reason to suspect that the fine wire plugs are defective.

So, what is causing the issues resulting in the TATI MSBs? There is good evidence in the data download given in the MSBs that at least the engine of the download was being operated in a condition that reduces the detonation resistance of the engine. The data download given is from a naturally aspirated SR22, again a curious choice for a SB intended for turbo-normalized engines. The MSB download chart is given below. The download shows a fuel flow of approximately 23 gph and assuming that the engine is producing 310 bhp, the specific fuel consumption would be .44 lb/bhp/ hour. This sfc is fairly close to best power and far from the .52 sfc that is the target 27.1 gph fuel flow in the SR22 POH. It is likely that the engine was developing more that 310 bhp since the download shows a pressure altitude of -200 feet and an OAT of less than zero at takeoff when the event occurred. The increased power will be in the range of 10% or 340 bhp, with a resulting sfc of .40 lb/bhp/hr, pretty close to peak EGT and certainly in the operation zone where detonation resistance is lowest. In short, the engine was not operated according to the POH, that it was probably leaned for takeoff, and that it was detonation that caused the cylinder failure.

Data Download for NA SR22 from TATI MSB 11-05

The TATI POH supplement for their turbo-normalized engine specifies for maximum cruise power that the engine operate at 2500 rpm, 29-29.6" MAP with a fuel flow of 16 to 18 gph. Although it may be possible to operate detonation free at LOP conditions, the transition to LOP from ROP passes through an operating zone where detonation can occur. It is most likely that the engines with cracked spark plug insulators were operated in detonation and that detonation is the cause of the insulator cracks. More on this mode of operation can be found in Lycoming SSP700.

It should also be noted that turbo-normalizing has a short operational history compared with normal turbocharger boosted engines. This short history coupled with LOP operation is, like most changes from normal procedures, fraught with new technical issues. Turbo-normalizing is sometimes offered as a means for maintaining sea level power at higher altitudes and this it does. What comes along with this is that at low altitudes (such as sea level), the engine does not have the same manifold (intake and exhaust) pressure conditions as the base naturally aspirated engine did. It is the nature of naturally aspirated engines that the exhaust manifold pressure is always greater than the inlet manifold pressure. (The difference can be reduced with well-designed aircraft inlet and exhaust systems but these effects are usually small.) In a boosted turbocharged engine operating at any significant (with respect to detonation) flight power setting, the exhaust manifold pressure is always less than the intake manifold pressure. This gives rise to an important difference in the detonation characteristics between NA and TC. In the NA engines, the high exhaust manifold pressure will keep some exhaust gas (residual exhaust gas) in the cylinder at the time of exhaust valve closing. Residual exhaust gases are detonation promoters. In the turbocharged engine, with the intake manifold pressure significantly higher than the exhaust manifold pressure, the residual exhaust gases are more completely cleared from the cylinder at the time of exhaust valve closing. This, along with the usually lower compression ratio, results in turbocharged engines having a greater detonation resistance than similar naturally aspirated engines. Turbo-normalized engines at low altitude have an intake manifold pressure close to 30" Hg. Because there is a turbocharger in the exhaust stream the exhaust manifold pressure will be higher than sea level and the cleansing of exhaust residuals will be low or even adversely affected (depending on system design and ambient conditions). A waste gate in the exhaust system of turbo-normalized systems certainly mitigates the high exhaust manifold pressure but because the turbo compressor must be driven, the exhaust manifold pressure will be relatively high. This high exhaust manifold pressure will result in a lowered detonation resistance in turbo-normalized engine compared to boosted turbocharged engines and this will be made worse by the usually retained high compression ratio of the base naturally aspirated engine.

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