Service Information Bulletin

airmotive engineering corp.

Title: **Effect of Over Temperature Operation and High Piston Blow-By on Cylinder Safety** *Technical portions are approved by Airmotive Engineering Corp.*	SIB No.: 12-2 Page: 1 of 8 Issued: 12/04/2012 Revision: 0

1.0 Purpose

The purpose of this bulletin is to inform owner/operators of the damaging effects of operating aircraft piston engine cylinders at temperatures above the CHT limits published in operators manuals and/or with high piston combustion gas blow-by. This bulletin provides some technical background related to the seriousness of over temperature operation and how to recognize and prevent these damaging operating conditions.

2.0 Background

There is a history of cylinder head separation from cylinder barrels over the years, and improvements have been made to limit the occurrences. The most prevalent failure mode is a fatigue crack starting in the root of the top loaded head thread at the interface of the head and barrel due to operation outside of the cylinder design envelope. This crack can propagate around the head until the remaining structure fractures in a single combustion load event. Photograph 1 shows one such failed cylinder. We should note that Head-barrel separation does not typically cause the engine to quit, but does reduce power and cause rough operation.

Airmotive Engineering Corp (AEC) has conducted laboratory and engine tests to isolate the factors that cause this particular head-to-barrel separation problem and have identified the technical reason these failures occur.

Photograph 1

The root cause of the head to barrel separation is the loss of interference fit between the head and barrel due to high operating temperatures. The effects of high operating temperatures are made worse by high piston blow-by.

The design of opposed aircraft engine cylinders for the majority of current engines have a cylinder head that is shrunk fit onto a cylinder barrel by heating the head and cooling the barrel before assembling them. Illustration 1 shows a cylinder cross section and cross sections of the head-to-barrel interface for Lycoming and Continental cylinders. Illustration 2 shows where many cracks initiate.

The area of particular importance to the physics of the assembly is the section of the head and barrel above the threads. This area is generally called the seal band area, but more appropriately, could be called the “friction” area. This is because this part of the assembly carries a significant portion of the load during normal operation through friction between the head and barrel.

AEC has been conducting laboratory and engine testing to isolate the primary causes for the head-barrel separation issue, and has validated the previously unsubstantiated root cause. This testing has involved laboratory fatigue testing with cyclic

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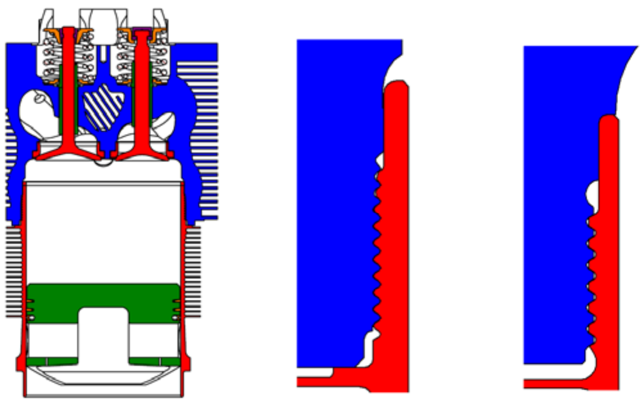
pressure loads developed through instrumented engine tests, and then engine tests where the cylinder heads were instrumented with miniature stress and thermal gauges at the critical locations.



Cylinder Cross Section

Head-to-Barrel Interface
Lycoming Continental

Illustration 1

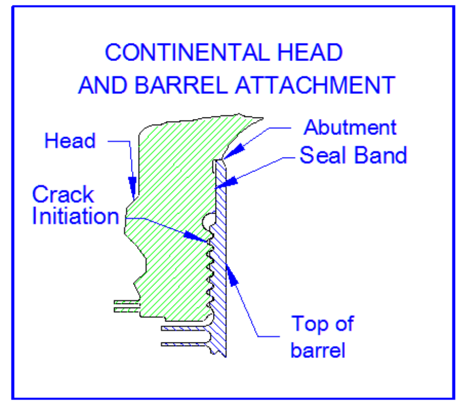


Illustration 2

The primary focus of the engine tests was to measure actual stresses at the critical area between the seal band and top thread. To accomplish this, a group of cylinder heads were machined to provide a range of assembly parameters that span the manufacturing tolerances of production cylinder assemblies. The cylinder heads had miniature strain gauges installed on the intake and exhaust side of the heads as shown in Photograph 2. Additionally, thermocouples were installed close to the strain gauges to measure the thermal environment at the gauges.

Photograph 2

Photograph 3

The cylinders were assembled and installed on a Continental TSIO-520-NB engine, which was then installed in an AEC test cell. Photograph 3shows this engine in the test cell ready for testing. This test cell has individual controllable cooling systems for each cylinder, so very precise temperature control can be maintained during testing.

The test data was plotted and then analyzed to determine how the stresses varied with temperature. The test data showed that stresses at the threads increase rapidly when the temperature exceeds the published CHT limits, with stresses then increasing rapidly with increasing temperature. The aluminum head has twice the expansion rate with temperature as the steel barrel, and as the head heats up, . Loss of seal band friction allows the combustion stresses to pass by the seal band and concentrate in the root of the first loaded head thread. This increasing stress can be sufficient to induce a crack in the top loaded thread root. Illustration 3 shows the variation of stress just above the threads with temperature.

Investigations of cylinders that have cracked in the top loaded head thread have shown that the vast majority have also had high piston blow-by, which also causes a heavy varnish deposit on the barrel bores called “glaze”. Because of these indications, AEC conducted additional testing by installing an instrumented cylinder using a barrel and piston that had experienced high blow-by in the field. The cylinder assembly was controlled to insure that it was dimensionally similar to the cylinder it replaced. This test phase revealed that the stresses in the cylinder with high blow-by were significantly higher than the cylinder that it replaced as shown in Illustration 4. We now know that poor break-in or other operational issue that causes high oil usage from piston ring blow-by is not just a nuisance, but can also be a safety issue.

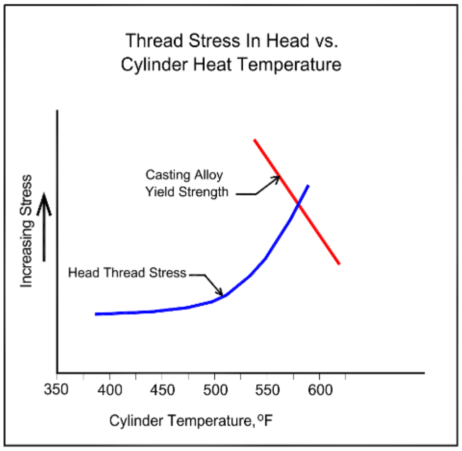


Illustration 3

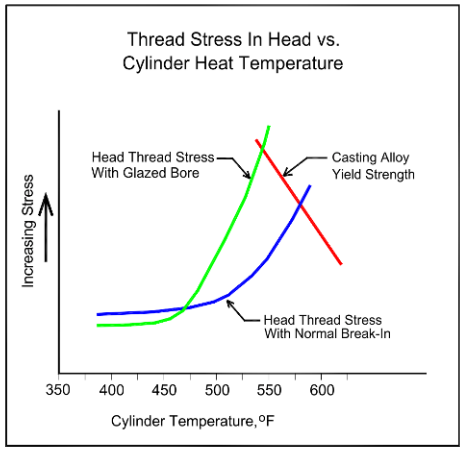


Illustration 4

3.0 Identifying Cylinders That Experience Over-Temperature And/Or High Blow-By:

High blow-by is most often identified by oil usage. AEC believes that the usage of more than one quart of oil in four flight hours could indicate high blow-by, and could have a significant impact on cylinder longevity. Often, high oil usage goes along with high cylinder head temperatures, and the existence of either should trigger further investigation.

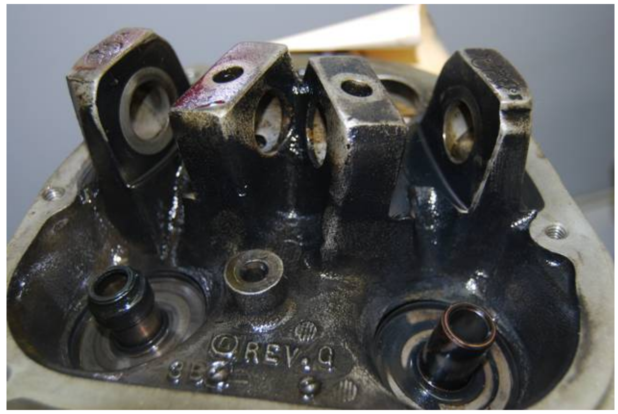
Evidence of high cylinder head temperature operation is not always apparent because the visual clues vary with operating factors, the most important being the time operated at the high temperatures. Additionally, the cylinder head can experience temperatures that increase rapidly until a failure results if the over-temperature condition is not caught and reversed. The evidence of short duration over-temperature will not always be evident in an initial inspection of the cylinder head or other components.

Distinguishing a cylinder that has been subjected to excessive high temperatures from a normal cylinder that has been operated for a much longer time frame presents challenges. Cylinders that are approaching the time for overhaul (TBO) will turn darker, and they may be darker if the engine has significant oil leaks.

Sometimes there is obvious evidence of over-temperature operation, and the following paragraphs show some comparisons that can be helpful to determine if longer term over-temperature operation has compromised the cylinder safety. A visual observation of the exterior of each cylinder will help identify conditions that could adversely affect the airworthiness of the cylinder assembly. The presence of a white to grey powder like residue may indicate leaking of combustion gases from the combustion chamber. However, this can also be caused by a leaking exhaust gasket, but should be evaluated and fixed regardless. If there is evidence of exhaust leakage that cannot be traced to a leaking gasket then the cylinder assembly must be removed for a comprehensive inspection.

Photograph 4 shows a cylinder with normal darkening in the rocker box after return for overhaul. Some darkening around the valve spring pockets is normal for the hours of operation. Photograph 5 shows a cylinder that has been operating very hot for an extended time frame. A cylinder that has been operated within thermal limits is shown in Photograph 6, and a cylinder that was known to be operating at and above CHT limits for an extended time period is shown in Photograph 7.

Photograph 4



Photograph 5

The area of the cylinder head around the spark plugs and the fin area around the exhaust port sometimes provides clear evidence of over-temperature operation. The visual clues can be caused by a leaking exhaust gasket, but can also be evidence of over-heating. Burned paint around the spark plugs on Lycoming cylinders or discoloration on Continental cylinders should be investigated to insure that high cylinder temperatures do not adversely affect air worthiness. High temperature indications around spark plugs can be caused by spark plugs that were not correctly torqued, or were somehow loosened, or by spark plugs with cracked insulators. There are other causes, but this condition should be investigated.

Photograph 6

Photograph 7

Photograph 8 shows a normal appearance for Lycoming parallel valve engines, and Photograph 9 shows a cylinder that experienced high over temperatures.

Photograph 8

Photograph 9

Skilled mechanics can distinguish one of the symptoms of high piston blow-by by looking at the condition of the cylinder bore through a bore scope. High blow-by will cause the cylinder bore to be coated with oxidized oil, which can often be identified through a bore scope inspection. Unfortunately, photographs can be difficult to interpret, so comparisons are not included in this bulletin.

An analysis of the operating conditions cylinders experienced is made easier after the cylinders are removed from the engine.

The top of the piston and the combustion chambers can provide great evidence of the nature of the combustion process and whether the cylinder was operating properly. Even minor detonation can cause some local surface melting, and the molten metal will be deposited in the vicinity of the detonation event. Detonation can progress to pre-ignition, which is generally much more damaging than detonation

Photograph 10 and 11 show a cylinder combustion chamber and piston that experienced detonation and possibly pre-ignition. Minor detonation can be tolerated for a short period, but it can grow in intensity as it heats surfaces in

Photograph 10

Photograph 11

the combustion chamber. The piston shown in Photograph 11 came from the cylinder shown in Photograph 10. The products of detonation and pre-ignition include splatters of bead-like deposits on the piston dome and on the combustion chamber.

Photograph 12

Photograph 13

Photograph 12 and 13 show another cylinder combustion chamber and the installed piston that experienced heavy detonation and/or pre-ignition.

One of the first places to look for evidence of over temperature operation is the underside of a piston. The underside of a piston is splashed and sprayed with engine oil during operation, and if the piston is operating too hot, which is usually caused by blow-by, but also high cylinder temperatures, then the oil will oxidize and deposit a coating of varnish, carbon and heavy oil as shown in Photograph 15. Photograph 14 shows a piston that operated for more than 350 hours during certification testing with the majority of the testing performed at 460 ˚F cylinder head temperatures.

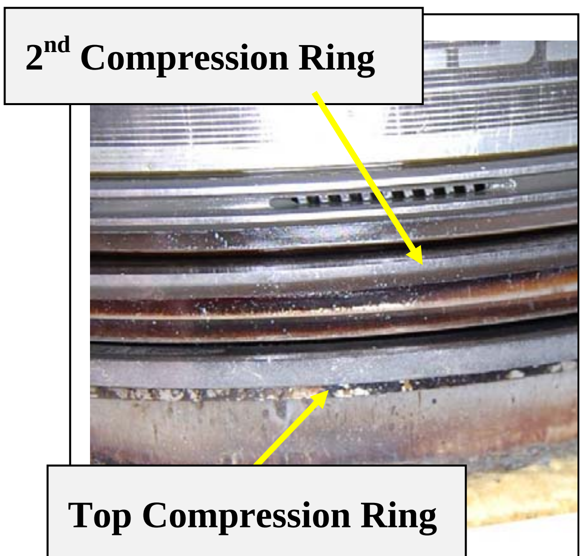
Photograph 14

Photograph 15

The outside of the piston can also tell a good story about the operating conditions. Photograph 16 shows a piston subjected to FAA endurance and durability testing. A total of 400 operating hours with the majority at CHT limits. Some minor detonation evidence is found on the dome, which probably occurred during detonation testing. Photograph 17 shows a low time piston that was overheated and experienced high blow-by.

Photograph 16

Photograph 17

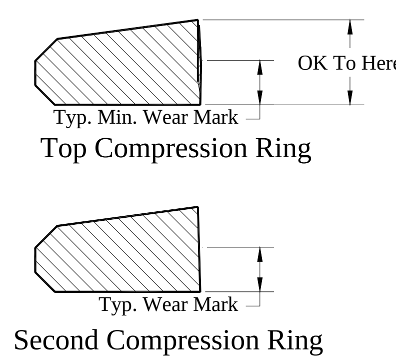


Photograph 18

Photograph 19

The piston rings also provide evidence of operating conditions. Piston rings that experienced normal break-in and operated at normal cylinder temperatures will show the following characteristics:

1. The top compression ring will have a wear band around the ring periphery extending from the bottom of the ring from ½ to completely across the ring face width.
    a. There is some variation in wear pattern appearance depending on the piston ring face geometry and coatings.



2. The second compression ring will have a bright shiny wear band that extends from the bottom of the ring to approximately ½ the ring face width.
3. The oil ring face rails will be shiny completely across the rail widths, but they will not have sharp lips or gaps in the wear indications.

The piston rings installed on a Piston for a Continental engine shown in Photograph 18 exhibit normal wear. The top ring has a molybdenum face, and close examination shows that the wear band extends from the bottom of the ring almost completely across the face. The second compression ring has a wear band that is about ¼ across the ring face. The scraper ring was installed with the taper toward the top of the piston, and the wear band is almost ½ the distance from the top of the ring toward the bottom. The scraper ring has a much sharper face taper than the compression rings, and will bed in faster than the compression rings.

Compression piston rings that have been subjected to high blow-by will be worn completely across the face, and will sometimes have sharp edges on the bottom of the ring face. Some that experience high blow-by for extended periods will have sharp edges on both top and bottom. Oil rings will have significant wear on the rails.

Photograph 19 shows piston rings that have experienced high blow-by. This piston did not have high operating time, but oil consumption was high. The bottom of the compression rings have a sharp lip that could cut a finger.

There are many causes for cylinder over-temperature. AEC suggests that owner-operators obtain copies of the articles written for Cessna Pilots Association Magazine and the EAA's Sport Aviation Magazine by Mike Busch for great perspective on the seriousness of cylinder over-temperature operation.

4.0 Summary

1. Head-to-barrel fit at minimum interference tolerance provides a safety margin for operation. However, the safety margins built into the cylinders can be lost when cylinder temperatures rise beyond published CHT limits.
2. A good cylinder barrel bore and piston ring break-in is essential for optimum cylinder life.
3. Current operating cylinders have a high margin of safety unless operated beyond CHT limits or have severely glazed cylinder barrels. No design, manufacturing or assembly practices can prevent failures from extremely high operating temperatures.
4. AEC highly recommends the use of a calibrated engine monitoring system that monitors and records cylinder temperature data for each cylinder. Most of these systems have alarms, and AEC recommends that the alarms be set at least 30° F below published cylinder temperature limits to provide a buffer to enhance safety. AEC cautions that the original CHT instrumentation for many airplanes monitors only one cylinder, and that these CHT gages can degrade over time due to resistance changes in the wiring and connections. Accordingly, AEC strongly recommends that CHT instrumentation be calibrated on a periodic basis.

5.0 Additional Information

AEC recommend viewing this document on-line, and zooming the color photographs and illustrations to get a clearer image to distinguish features discussed.

Contact the ECi Customer Service Department at 210-820-8100 for additional information and to report any significant findings that could assist in the quest to provide the best and safest cylinders possible.