Shell Aviation

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Dear Aviators,

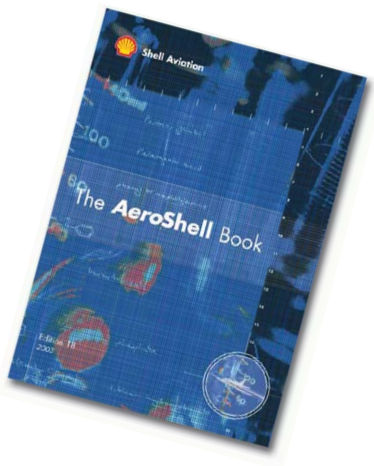
It has been a number of years since Tech Talk first got published and distributed via the Aviation Trader. Many good articles have been published over the last 17 editions and some many of you might have missed or lost over time. Below is a list of articles I mention, and if you would like to receive a copy, please drop me an email and I will be happy to send it to you.

1. Multigrade Oils
2. Oil Analysis -
   Health check for your engine.
3. Greases -
   What are they and how do they differ.
4. The Future of GA fuels
5. W100 Plus - Plus what?
6. Engine Preservation Oils
7. Removing your aircraft from storage
8. Oils for Microlight Engines
9. I like to use a multigrade Oil (Q&A)
10. Frequently asked Questions
11. Base Oils
12. Questionnaire
13. How to buy from Shell.
14. Multigrade Oils in Hot climates
15. Detonation and Pre-Ignition
16. Alcohol in Aviation
17. Managing Engine Temperatures.

In this the 18th edition of Tech Talk we cover Engine Cam and Follower Damage. Rob Midgley points out that it is not uncommon for cam and follower damage to be the cause of light aircraft engines failing to reach the Time Between Overhaul TBO). Rob discusses 3 main causes of the initial damage: Corrosion, Scuffing and Fatigue.

Please continue with your feed-back or suggestions for any future articles you would like Tech Talk to cover.

Happy Flying,



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AeroShell TECH TALK

Engine Cam and Follower Damage

What causes it, and practical steps to avoid it in your engine

Corrosion

Corrosion is easy to understand and tends to affect those engines which are not used as often as they might. There are a number of mechanisms, but all are associated with water condensing in oil, or on engine internals, often due to lack of use. The best way to avoid this is to fly frequently – the engine manufacturers recommend once every 2 weeks. If this is not possible, then consider using an oil containing a corrosion inhibitor, such as AeroShell Oil W 15W-50 or AeroShell Oil W 100 Plus. We shall see later that independent testing has shown that AeroShell Oil 15W-50 is the most effective multigrade on the market in terms of anti corrosion and anti wear, and AeroShell W100 Plus benefits from the same additives in a single grade oil. For long term storage, a dedicated preservative oil should be used, such as AeroShell Fluid 2F.

Scuffing

Scuffing damage is caused when two moving parts come into contact with each other. This can cause damage to the surface through a plucking and scouring action. The high heat generated by the metal to metal contact causes local welding of the parts, which plucks metal from the surfaces. The relative motion of the parts then further damages the surface resulting in the characteristic surface scoring which is associated with scuffing damage.

Scuffing damage can, again, be associated with long periods of inactivity. Oil drains to the bottom of the engine during periods of inactivity, leaving little residual on the engine components. When the engine is next started, the engine is running with this limited residual oil supply, whilst the oil is being pumped up from the bottom of the engine.

The cam and follower in most aviation engines, is the last place to receive fresh oil supply. When an engine is started, oil is pumped “uphill” from the bottom of the engine, through the oil pump, through the oil cooler, through the filter, into the main oil gallery where it is pumped to the engine bearings, then on to a second gallery, which feeds the hydraulic adjusters on the cam followers. Once the oil supply has reached these areas, any residual oil from the supply to the main engine bearings is left to splash into the crankcase where it must lubricate the pistons, piston rings and also hopefully, the cam. So you can see that oil flow is critical here as there is a long and tortuous path to follow before any oil reaches the cam. The engine may be running for a considerable time, even with apparently full oil pressure on the gauge, before oil reaches the space between the cam and follower. This is why single grade oils designed for use in high temperatures should not be used when the weather turns cold. The more viscous the oil at low temperature, the longer it will take to pump around the engine, so the components can be reliant on the residual oil film for some time before the normal oil supply is provided. The problem of poor oil circulation can be exaggerated in cold ambient temperatures, and it is here that multigrades can be a distinct advantage.

Additives can help too. Shell Aviation uses an anti scuffing additive in some of its oils, which can help prevent this type of damage. This additive does two things. Firstly it improves the film strength of the oil, so any residual oil in the engine is better able to keep parts separated, thus preventing the damage from occurring in the first place. Secondly, the additive reacts with the metal surfaces to protect them from scuffing damage even if metal to metal contact does occur. Shell blends this additive into 2 of it’s aviation piston engine oils at this time - AeroShell Oil W 15W-50 and AeroShell Oil W100 Plus - the same oils that contain the corrosion inhibitor.

Metal Fatigue

The final form of damage, metal fatigue, is less easy to understand, but is often what is seen as the final stage of wear on a cam and follower. Damage from metal fatigue is often seen on cam followers as pitting of the surface. If the follower is sliced in two and the pits are examined closely, then small cracks appearing from the bottom of the pits are seen; this is characteristic of fatigue damage. So what is Metal Fatigue?

Failure Mechanism

Metal Fatigue is a phenomenon in which cracking, or failure of a metal part, will result from applying a varying stress over a large number of cycles. To help understand this better, let’s first answer the question “What is stress?” Stress is nothing more than load per unit area on a part, so increasing the load on a part, or decreasing it’s area, will increase stress. So in some ways stress can be thought of as being comparable to pressure.

For metal parts, such as steel, the increasing stress will make the material respond in different ways. Initially the metal will act elastically. This means that the material will deform depending upon the stress applied, but return to its original dimensions when the stress is removed. This can be imagined as behaving in very much the same way a spring normally would – hang a weight off a spring and it extends, remove the weight and it returns to it’s original size. It behaves similarly in compression. Above a certain stress level, the material will start to “plastically” deform. This stress level at which this happens is known as the “elastic limit”. If we use the spring example again, then one can imagine overloading the spring so that it stretches and no longer returns to it’s original size. This is plastic deformation.

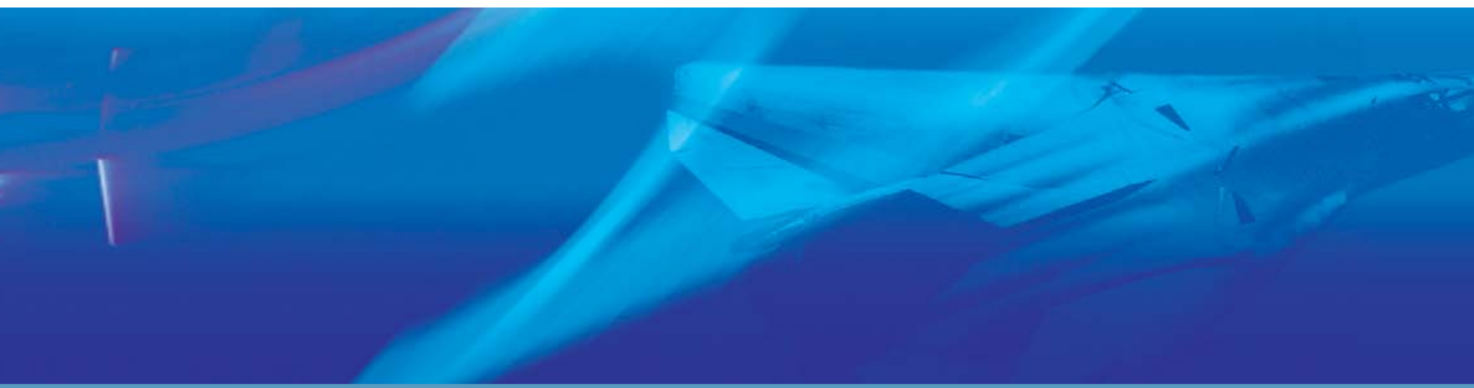
The final step is failure. This is when the material breaks, and is known as the Ultimate Tensile Strength.

It has been known for many centuries that fatigue exists, but was always associated with stress levels above the elastic limit. This is how most people think of fatigue and is what happens in the often used example of a paper clip; we can all imagine bending a paper clip repeatedly until it breaks. This is a cycling stress, but what is significant here is that the paper clip is deformed with each cycle beyond its elastic limit i.e. it does not return to it’s original shape each time it is bent.

What was not appreciated until the 1940’s is that fatigue failure can also exist if the load applied is below the elastic limit of the material. In the paper clip example, if you were patient enough, then you could break the paper clip if you cycled the load without bending the metal at all. It would take several million cycles, but it could be done.

This is where it becomes significant in an engine. The most obvious place that we have a cycling load is between the cam and follower. The cam is so shaped that, as it rotates, it will push the follower against the pressure of the valve spring, to open one of the valves. As the cam rotates further, the cam profile falls away and allows the valve spring to close the valve, moving the follower back to its original position. So the load on the cam and follower increases as the valve is opened, and decreases as it closes. Ideal conditions for fatigue it would seem.

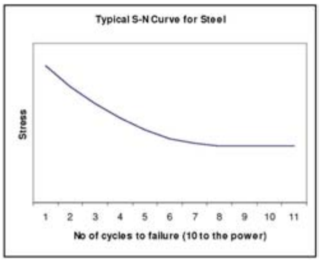
This is where the engine designers come into the picture. They have a fixed load to contend with, between the cam and lifter, and a known engine life (TBO). It is their job to then lower the stress so that the parts can reach their planned life without suffering from fatigue. How do they do this? The answer is by



increasing the surface area of the cam and follower. Remember stress is load per unit area, and the load from the valve spring is fixed, so increasing the area for a given load reduces the stress. The obvious question is how do they know what is an acceptable level of stress?

Predicting Fatigue Life

Fatigue is not an exact science. However there are data available, drawn from practical experimentation, which is used to predict the number of cycles to failure for different stress levels in a material. These are known as Wohler S-N plots (S for Stress, N for Number of cycles). These are simply plots of stress on the vertical axis and number of cycles on the horizontal axis. A number of material samples are tested at different stress levels, and the points at which they fail are plotted to form the S-N curve. A typical curve for Steel is shown in the attached figure.



As we have already mentioned, fatigue is not an exact science. This S-N curve can not be used confidently to predict the failure of a component, as other factors have influence such as surface hardness, surface finish and the variation in the microscopic structure of the material. What is represented by the S-N curve is the 50% survival life of a part, so it represents a probability, rather than a certainty, of failure. So the safe thing for the design engineer to do is to reduce the stress level to give a predicted fatigue life somewhat beyond that needed.

What is really interesting about steel is that, unlike other metals, the curve flattens out below a certain stress level. This point, known as the "endurance limit" is significant as it means that below a certain stress level, the steel has a theoretically infinite fatigue life. This endurance limit tends to be around 107 cycles (or 10 million cycles), which for our cam is about 150 hours at an engine speed of 2500 rpm (remember the cam rotates at half engine speed).

If the designer calculates correctly, then at stress levels below this value should mean infinite fatigue life, so, simplistically, the area of cam and follower is increased to reduce the stress so that it is significantly below the endurance limit for the material. So how is it then that we ever see fatigue damage in real engines?

Surface Damage

If an engine suffers scuffing damage from a dry start, which we covered earlier, then the surface of the cam and followers becomes ridged and no longer smooth. These microscopic ridges and valleys in the metal will result in the stress not being evenly distributed over the surface of the parts. This means that there will be variations in the stress level on the surface of the cam and follower, which can lead to stress concentrations. Surface corrosion can cause similar stress variations too.

So what may start as a scuffing problem due to inadequate oil supply at engine start, may display itself as a fatigue problem several years later.

Thin Oil Film

When the engine first starts, especially after a period of not being used, we have seen that the engine internals are initially reliant upon any oil remaining on the parts since the last engine run. The oil available at the cam face is typically not as much as would be present during normal operation, and so the oil film can be abnormally thin. This leads to an increase in load transfer between parts, and so increases the stress. Once normal oil supply reaches the cam then the oil film increases and the stress drops, so once again, having oil supply reach the cam as quickly as possible is significant.

Another more obvious situation where thin oil films can be a contributing factor, is using too low a viscosity grade in high ambient temperatures, for example using an 80 grade oil in hot summers.

Hydraulic Adjusters

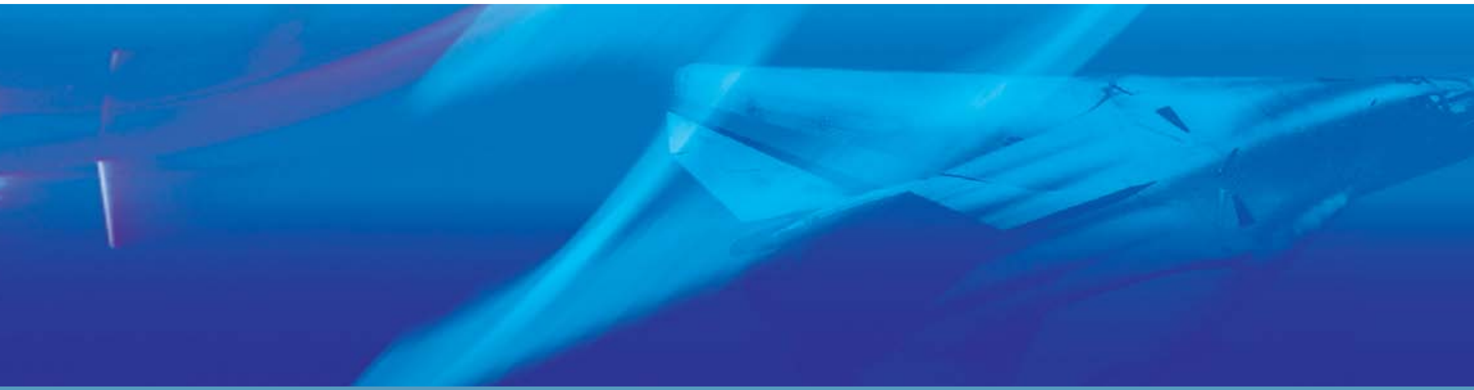
The cam followers in most aviation engines use oil pressure to automatically adjust the gap between the cam and follower. If the oil has drained to the bottom of the engine whilst it has been sat unused, then the followers may be out of adjustment until fresh oil is supplied by the oil pump. If the followers have too large a gap between them and the cam face, then the cam impacts the follower sharply on the steep part of its profile, rather than gradually lifting the follower as happens in normal operation. This increases the stress on the parts, and can reduce their fatigue life. So, again, the engine is dependent upon the rapid supply of fresh oil, especially after a period of inactivity.

How do we prevent fatigue damage?

The key is maintaining full oil supply throughout the oil system, so frequent use is the best defence. This is not always possible of course, so then using an oil with corrosion inhibitor and anti scuffing additive can help prevent the initial surface damage of the parts, but making sure that there is adequate oil coverage on the parts is critical too.

In cold weather, it is better to use a multigrade with as low a viscosity as possible at start up. AeroShell Oil W 15W-50 is designed with just this in mind. The first number of a multigrade designation tells you something about the viscosity of the oil at low temperature (the upper number indicates the viscosity at high temperature). So a 15W-50 will have better low temperature flow characteristics than a 20W-50 for example, meaning that oil reaches all parts of the engine just that bit quicker.

So this works well for low temperature, but what about in hot summers? Well multigrade can be used here too but, for infrequent use in hot climates, single grade oils, such as AeroShell W 100 Plus, can also perform well. AeroShell Oil W100 Plus contains the corrosion inhibitor and anti scuffing additive of the multigrade, but does not have the same low temperature flow properties. So how does this help then? In warm climates (at least above 15 deg C) then the single grade oil will be fluid enough to circulate reasonably well on start up. The advantage is that, during periods of inactivity in warm weather, less oil drains into the bottom of the engine when compared to multigrades, so there is more residual oil left on the component parts. In this way, the engine is less reliant upon oil circulation when the engine is first cranked over. In addition, the single grade W100 Plus tends to leave a thicker residual oil film, when compared to multigrades, which we have seen helps reduce the stress



transfer between parts.
Because of this, we see many customers using AeroShell Oil 15W-50 in the winter, and the less expensive AeroShell Oil W100 Plus in the summer.

Practical Steps

What the operator does also has a profound affect upon engine longevity, especially with infrequently used engines. For example, help can be gained with an engine which has not been used for some time, by pre oiling prior to start. The easiest way to do this is to remove one set of spark plugs, which will allow the engine to turn over more rapidly on the starter motor. With the fuel off and mixture at idle cut off, turn the engine over on the starter motor. This should allow the engine to turn over quickly enough for the oil pump to distribute fresh oil around the engine and ensures that oil pressure is available immediately on start up. This means that the engine is less reliant upon additives to protect the parts and the risk of engine wear is limited in the critical period immediately after engine start.
Just as a word of warning if doing this, take care to look at your Pilot's Operating Handbook to confirm the maximum length of time you can operate the starter motor before allowing it to cool.
As soon as the engine starts, do not let the engine race. Even if oil pressure is seen on the gauge, it may be some time before the oil fully circulates around the engine, so I would recommend selecting an initial idle speed which is as low as possible, but which still allows the engine to run smoothly. I have found that this is normally around 800 rpm. Keep at this engine speed for 20 seconds after full oil pressure is seen on the gauge and only then move to the more normal idle 1000 –1200 rpm.

Selecting oils - Understanding the Problem

We now have an understanding of how fatigue affects our engines, and how it occurs. We can see that additives can help, but what happens when the engine is first started is also critical. We can also better appreciate what we need to look for in an oil.
Having a better understanding of the mechanism helps to decide whether performance testing of oils show the whole picture when relating to fatigue. One test method seen recently compares oils by running a cam and follower continuously in a test rig but, critically, involves increasing the valve spring tension to 50% overload. This overload condition is intended to reduce the duration of the test, but as you will appreciate, looking back to the S-N curve for steel, this arbitrary increase in spring force will increase the stress by 50% and potentially bring the stress level above the endurance limit for the material.
Remember that the line on the S-N plot represents the 50% failure line. If above the endurance limit, then the test brings us into an area where the unpredictability of the fatigue takes effect, so some specimens may fail after a given time, and other apparently identical samples may not. It is for this reason fatigue testing results will normally always be presented after statistical analysis of many samples, and not by individual results.
The more critical question to ask yourself when looking at any testing data is "is it representative of what happens in real life?" For example, in this case, can a spring force increase by 50% in a real engine? If the testing does not take into account the affects of engine starting and stopping, which it does not in this instance, then does this reflect how you use your engine? Hopefully this piece will leave you better able to make up your own mind about what properties are important to the way you operate your engine when selecting oils.

Summary

So to sum up, how do we avoid cam and follower damage?
The best way to avoid damage is to fly frequently and with an oil grade which is approved for the temperature that you are operating in; this is by far the best way of avoiding damage. Oil recommendations can be found in the Lycoming Service Instruction SI 1014, or Continental Service Information Letter SI 99-2. In cold weather use an oil with good low temperature flow characteristics, such as AeroShell Oil W 15W-50.
If the engine is used infrequently, then consideration should also be given to using an oil with corrosion inhibitor and anti scuffing additive, as well as considering the viscosity of the oil to be used. Regardless of your oil choice, if the engine has stood for some time, then think about some practical steps to help make life easy for your engine in those first few seconds after start.
As you will appreciate, there is a lot of work that goes into formulating oil and Shell Aviation has tried to look at the requirements of engine operators and offer products which meet the demands of real world operations. Shell Aviation was the first to introduce modern additives and semi synthetic technology into aviation oils. In recent testing carried out by the independent Aviation Consumer Magazine* AeroShell Oil W 15W-50 was shown to out perform all of the competing multigrade oils. The testing compared both the anti wear and anti corrosion properties of AeroShell Oil W 15W-50 and other similar, modern multigrades on the market. The AeroShell Oil exceeded the performance of the other oils in every test category. This, combined with what is still class leading low temperature flow properties, gives the best chance of protection from all forms of cam damage, especially in colder weather.
Even though this testing was carried out by an independent body, and not influenced at all by the oil companies, it can be argued that bench testing only counts for so much - so AeroShell's multigrade has also been tested under the most demanding of conditions - more than 15 years of successful operational service – to give you a product which you know you can depend upon.

* Aviation Consumer Magazine covered the aviation oils testing in their October and November 2002 issues. Back issues can be ordered from their web site www.aviationconsumer.com

Shell Aviation