ENGINE OVERHAUL LIFE AND OPERATING 'ON CONDITION'

This technical leaflet tackles the issue of engine overhaul lives, how to give your engine the best chance of achieving reliability for its full overhaul life and the possibility of operating it 'on condition' beyond the manufacturer's recommended TBO.

This TL was introduced in response to comments made during the LAA's 2011 Ageing Engines Seminar, when inspectors present at the forum were keen to see the LAA paperwork better supportive of the need for long-term maintenance planning and engine condition monitoring.

This TL is intended to help inspectors and owners to feel more confident in their assessments of engine condition and less exposed to litigation in the unfortunate event of an accident following engine failure.

Whether it's a ten year old Rotax or a seventy year old Gipsy Major, many of us operate aircraft engines that are beyond the first flush of youth. We all want to fly safely – how long can the engine be trusted to deliver? How should we regard the overhaul life which the engine manufacturer suggests? Is it safe to operate 'on condition' past TBO? What about buying an aircraft with an already 'on condition' engine – is this a recipe for disaster?

There's considerable variation around the world on the treatments of manufacturer's engine lives on aircraft engines. In America, where most of our certified aero-engines are manufactured, the manufacturer's TBO is regarded only as a recommendation and owner/operators are not obliged to follow it.

Our neighbours in France, on the other hand, treat the manufacturer's TBO as sacrosanct. In the 1970s and 80s this resulted in literally hundreds of Jodels, Emeraudes and Cubs becoming almost valueless in French flying clubs, because their perfectly serviceable but 'time expired' engines cost more to overhaul than the airframes were worth at that time.

Fortunately for us in the UK, our authority has a more pragmatic approach to TBO than the French, under which engines in many private aircraft are allowed to operate 'on condition' past TBO. This allowed many of these French aircraft to be imported over here, where with careful use, many of these engines have achieved many more hours of reliable service before an overhaul finally became necessary, or another engine substituted.

For C of A type light aircraft (less than 2730 Kg MTWA and 400 horsepower), the procedures relating to extensions past TBO are promulgated in Generic Requirement GR 24 of CAP 747, 'Mandatory Requirements for Airworthiness', which can be downloaded off the web as a pdf. GR24 also provides a guideline for 'on condition' running in permit aircraft.

In a nutshell, the procedure in GR 24 involves:

- Regular monitoring and recording of critical engine health indicators such as oil pressure, maximum static RPM, magnetic plugs and filters so that owners and their inspectors can be alerted to any signs of impending internal failure.

- It's also important to check that any airworthiness directives normally specified as mandatory at overhaul have been carried out on an engine running 'on condition'. In other words, the delay in overhauling the engine is not an excuse to delay carrying out an AD.

- The engine must have been installed in a G-registered aircraft, or one from another EU member state for at least 200 flying hours prior to being allowed to run 'on condition', this precludes people who want to import a C of A aircraft with a 'time-X' engine from the States, or, for that matter, just a bargain high-hours engine.

- Not all engine types are eligible
- Eligibility depends also on the type of aircraft operation ie private category/aerial work.

The TBO for an engine is usually established by the manufacturers carrying out test-bed endurance programs where the engine is run day and night in a silenced chamber, cycling through a specified and purposely over-punishing schedule of so many hours at full power, so many at idle, so many at cruise etc. The test is usually run with the engine set up to create worst-case conditions, for example the cooling systems are adjusted to run at cylinder head and oil temperatures only just below 'red line', the fuel and oil are lowest-spec. and so on. The engine is stripped down every couple of hundred running hours, all parts are inspected for any signs of developing faults, a report written up and then the engine is reassembled (without replacing anything) and the test continued. These cycles carry on until either something fails in a big way, or a worn part has become clearly on the verge of failure, or the manufacturer runs out of patience and decides that enough is enough. The TBO is then agreed between the manufacturer and the certificating authority by applying a mutually agreed factor to the final total of hours accumulated in the test. Later on, as experience with it is gained, the TBO is often increased and calendar lives imposed based on the actual results in the field.

Of course, determining the TBO in this fashion is a pretty 'blunt instrument' for dealing with what is in reality a much more complex equation. Engine condition is generally much more determined by the way an engine is used, maintained and stored, type of oil and fuel used etc than by the number of years or number of hours in service.

During the manufacturer's tests the engine is run on the test bed in a manner which is purposely more severe than a sympathetic operator will use, for example going straight from sustained full power to idle without any gradual cooling-off period. And the schedules usually specify a greater proportion of high power running than a typical light aircraft flight will involve, unless it's in a pylon racer or an overweight flying barn-door.

Then again, the tests are done in almost continuous use crammed into just a few months. The tests don't take into account the damage that accrues due to most private aircraft being very little used through the winter, when over time the oil film breaks down and internal corrosion takes hold, aided and abetted by internal condensation and the combustion products having turned the old oil acidic. Nor do the tests replicate the frequent starts and stops of a tinkering owner, where over-priming of the engine to start it may wash the oil off the cylinders and cause more wear in each start-up than hundreds of hours of normal use. And of course, running with cold oil often causes more problems than hot, because cold oil doesn't boil off the condensed water inside the engine, leading to a build up of watery corrosive sludge.

Despite these reservations, the TBO is the engine manufacturer's best shot at saying how long he thinks the engine should run reliably before needing a total strip. In the ideal world, once the engine reached 'TBO' we'd have it overhauled.

Figure 1 shows the overhaul lives of some of our most common engines in the LAA fleet, and where further information can be found on each. You'll notice that most manufacturers specify a calendar life as well as hours of operation, and with the low utilisation inherent with most privately-owned aircraft, the calendar life often 'runs out' long before the hours have reached their TBO limit.

But overhauling an engine is a toe-curlingly expensive business, and for many vintage engines there's such a shortage of spare parts that to insist on a full overhaul would mean the aircraft was forever grounded for lack of parts. Luckily, there's plenty of evidence that with appropriate operating procedures, maintenance actions and careful condition monitoring, most types of aircraft engines can continue to operate long beyond TBO without an undue risk of sudden in-flight failure. For most low-stressed engines, when parts finally wear out this can usually be picked up through vigilant condition monitoring long before the issue becomes safety-critical.

Where the subsequent investigation involves the engine's 'bottom end' being taken apart (for example to replace a worn camshaft or main bearings) this is the point where the decision is normally made to call it a day and have the engine overhauled, or at the very least, fully internally inspected and all worn out parts replaced.

Another keystone of the 'on condition' philosophy is that if an engine that's 'past TBO' comes apart to replace components damaged in an accident, such as a shock load, then this should instigate a full inspection or preferably a full overhaul. It would be wrong to just slip in a new crankshaft and bearings and miss the opportunity to measure up all the other 'bottom end' parts exposed when the crank case is split.

As an aside, it's worth stressing that there's a difference between a full overhaul and a strip inspection, replacement of worn parts and rebuild. A full overhaul doesn't return the engine to 'as new' condition, but it does include the replacement not only of parts found to be worn outside of limits but also a long list of components which the engine manufacturer specifies must be changed whether they're damaged or not. This list of parts has a cost implication, of course, and for older engines also raises issues of availability. When an engine is stripped down the cost v's benefit of going the extra mile with a full overhaul as against an inspection and rebuild is a matter the owner needs to think about carefully.

Not all engines are suitable for running 'on condition' more than 20% beyond TBO. Some, particularly highly-stressed ones suffer from progressive fatigue crack damage to crankshafts, pistons or other vital parts which are undetectable externally, but if kept in service for too many hours use, eventually the part breaks suddenly leading to an engine failure without warning. Only through in-service experience in the field can an engine type's long-term bottom-end longevity be determined.

GR 24 shows that the CAA prohibit on condition operation significantly past TBO for all Rotax, Thielert and Mid-West engines and also specifies particular modification states of Gipsy Major crankshafts that are required if they are to be allowed to continue past TBO. LAA take a more relaxed approach to the Rotax engines, on the basis that different models of Rotax have now established a reasonable history of operational use in scores of different installations. Linked with this, LAA take the view that different classes of aircraft and types of operation justify different approaches to engine reliability expectation. For example a four seat retractable needs a different reliability threshold than a single seat microlight.

There are other particular long-term airworthiness issues associated with common types of engine, which it's important that owners are aware of in deciding how long to keep their engines in service and when critical parts are replaced.

These include:

- corrosion and spalling of Lycoming camshafts and cam followers especially for engines that have been out of use for long periods without being inhibited
- corrosion-induced cracking of Jabiru and HKS valve stems particularly if run with sustained high EGTs
- the fatigue failure of early Rotax 582 two-stroke crankshafts particularly if subjected to excessive high-power running. Later type (618 style) crankshafts seem not affected in this way.

- pounding-out of the centre main bearing on VW crankcases when big-bore engines are overloaded by oversize propellers
- propeller flange fatigue failure on non-aerobatic models of Lycoming flat four engines when used in aerobatic aircraft, especially when metal propellers are used.

These types of issue obviously affect the decision as to how long to keep one of these engines in service. For example, clearly it would be folly to ignore a manufacturer's recommended replacement of valves when the engine type has a history of catastrophic valve stem failure. The damage done by a dropped valve, and the risks induced by the associated sudden engine stoppage are out of all proportion with the cost of new valves and a top overhaul.

Within the LAA fleet, it's the owner's responsibility to keep his aircraft airworthy. But the inspector charged with signing the permit to fly renewal paperwork has to decide whether he is satisfied with the owner's judgement that the engine remains airworthy, especially if the engine is running 'on condition' past TBO. In making these judgements, owners and their inspectors should take into consideration:

- the overhaul history of the engine
- the maintenance history of the engine
- the quality of the maintenance records
- the kind of life it has led since overhaul – accidents, periods of neglect etc
- the results of condition monitoring checks
- the application in which the engine is now in use

Depending on the type of engine, many different parameters are used for monitoring the internal health of an engine in service. These include, for example:

- max static RPM
- rate of climb at MTWA, best climb speed
- oil pressure at particular cruise RPM and oil temp
- hot oil pressure at idle
- oil consumption
- compression in each cylinder
- appearance of spread-out full-flow oil filter element
- appearance of magnetic plug
- for pump-fed engines, fuel pressure at a particular RPM
- for two-strokes, big end/small end wear test result
- with VP props, airspeed at a given RPM and manifold pressure
- with Cirrus and Gipsy engines, a measure of magneto drive train backlash by a crude measure such as estimated movement at the visible surface of the Simms coupling
- with engines with manual tappet adjustment (eg VW and early Jabiru), number of 'flats' of adjustment needed to restore correct valve clearance

Note – many of these trends will be upset by any change in propeller type or fitment of the engine in a different airframe. Effective conditioning monitoring 'through' such major changes is very difficult or impossible.

A fictional sample set of engine condition monitoring results is shown in figure two, and some of the parameter displayed graphically in figure three, which illustrates how much easier it is to see what's happening in a graphical presentation. This is one C90 which is clearly showing several disturbing trends developing and due for internal examination and probably a full overhaul before the 2011 'renewal'.

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In conjunction with this technical leaflet, our website now includes an Excel spreadsheet which owners can download if they wish, fill in selected parameters from their annual engine test results on the electronic table and be presented with automatic graphical illustrations of the trends as they develop year on year, both for their own consumption and to present to their inspector.

The data needs to be carefully collected if it is to be meaningful. For example, oil pressure needs to be checked at a consistent rpm and oil temperature. A particular VW engine in a Turbulent on our LAA fleet has been in service for almost 40 years, and the owner checks regularly that on straight SAE 30 oil at an oil temperature of 70 deg C it continues to give 37 psi oil pressure at 2700rpm. At 650 idle rpm with hot oil the pressure is less than 10 psi, and has been for years, without apparent ill-effect.

By identifying the critical parameters and displaying the ongoing successive results at each 100 hours, or each annual check on a single sheet of paper, rather than spreading them throughout the logbooks in assorted and often haphazard entries, it should be much easier to spot whether the engine is remaining 'on form' or whether any of the trends have taken a critical down turn.

Diligent operators may find they can back-populate such a tabulation to a reasonable degree from logbook entries, plus any retained daily records of flying, oil uplift and so on.

Ideally, owners should start to record data before TBO. The norm really needs to be established in that high reliability bottom region of the 'bathtub' curve, after the 'infant mortality' phase but before incipient wear-out starts to show in oil pressure, oil consumption, etc. We recommend that a good track of parameters should be kept from half TBO, and certainly from 2/3 TBO to support further running after TBO is reached.

In truth, the awareness that comes with this kind of health monitoring will help owners to get aging engines to reach TBO (in hours terms), let alone beyond it, for in reality with many engines it's a struggle to keep them going to TBO. With spares often next to unobtainable, it's even more vital to keep components from getting damaged. The time to find that you've got a blowing head gasket is BEFORE those sealing faces get irreparably damaged, or the head cracks, not at the next annual check when the damage has been done. One owner relates how he found a very light exhaust valve leak while compression testing a Gipsy Six, caused by a build up of carbon deposits in a valve guide making the valve stiff to move. Running the right size reamer through the valve guides cleared them out and probably staved off a valve sticking problem later, nipping a potentially serious safety issue in the bud.

Differential compression testing is not always easy to carry out in the field - getting a hot engine and a good air supply in the same place at the same time can be quite a problem – but there is much to be gained with old engines which can blow head gaskets, suffer cracked heads, or have latent issues with valves or seats. With the cylinder pressurised one has all the time in the world to track the source of any excessive air leaks, whether via the exhaust valve, past the rings (giving a flow at the crankcase breather), or as indicated by soapy water bubbles from a joint or crack. It's a good idea to see that a newly fitted head gasket is effective by doing a compression test even before the first run. The absolute reading is almost academic because one quickly develops a feel for how a given engine type responds and sounds with 80 psi applied to the cylinder and the piston not quite at TDC. 'Feel' alone seems to work rather well when the cylinder is pressurized from a compressor, (be sure to restrain the prop) but as the gauge is there one might as well read it. Other enthusiasts manage without an air supply, simply by turning the engine by hand and feeling the amount of 'bounce' in the propeller, but its much harder to work out where leaks are occurring with this method.

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When in-flight engine problems do occur, often it's due to the accessories rather than with the core engine. The engine condition monitoring form included here also gives an opportunity to record the age and overhaul history of the critical engine ancillaries such as magnetos, carburettors, fuel pumps etc. so that owners and inspectors can keep track of these sometimes neglected but vital components. Running an engine 'on condition' and delaying the full overhaul means it's even more important to keep up to date with all the other engine maintenance, keep on top of the AD status etc.

As far as buying an aircraft with an 'on condition' engine (or any used engine for that matter) is concerned, when an aircraft changes owner or inspector, the new incumbents, hopefully mindful of the 'caveat emptor' warning in every LAA magazine, will not necessarily be happy to take everything at face value, be it a shiny coat of paint, an EASA Form 1 or an owner-compiled engine monitoring spreadsheet. Even in the certified world, an aircraft coming to a maintenance organisation for the first time will typically be inspected in great detail and at eye-watering expense. Take nothing for granted, for some excellent aircraft have poor paperwork, and some godlike paperwork is produced for dog-eared aircraft, and there's everything in between.

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Figure 1

PUBLISHED TBOs FOR COMMON ENGINES, AND WHERE TO FIND MORE DETAILS

Make	Reference	Model	Notes	TBO Hours	TBO years
Cirrus	SI F6	Minor		800	
Continental	SIL 98-9	A65, A75		1800	12 years
		C75,C85, C90		1800	12 years
		0-200, 0-300		1800	12 years
DH	RR TNS G15	Gipsy Major	1,4	1000/1500	nil (except Public Transport)
Hewland		AE75	10	600	nil
Jabiru	JSB 001-1	2200A	5,11	1000/2000	
	JSB 001-1	3300A	6,11	1000/2000	
Lycoming	SI 1009	0-235	1	2000/2400	12 years
		0-290	1	1500/2000	12 years
		0-320	2	1200/2000	12 years
		IO-320	1,2	1200/1800/2000	12 years
		AIO-320		1800	12 years
		AEIO-320		1800	12 years
		0-360	2	1200/2000	12 years
		IO-360	2,3	1200/1400/2000	12 years
	(200 BHP)	AIO-360		1400	12 years
	(180 BHP)	AEIO-360		1600	12 years
	(200 BHP)	AEIO-360		1400	12 years
Rotax		2 strokes		300	5 yrs
	SB912-004UL	912-UL	7	600/1200/1500	10/15 yrs
	SB912-004UL	912-ULS	8	1200/1500	10/12 yrs
	SB914-027UL	914-UL	9	1000/1200	10/12 yrs

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Notes for Figure 1

1. Depending on precise model and build spec – see reference.
2. Only engines with ½" diameter valve stems rather than 7/16 may qualify for the higher TBO.
3. Depending on precise model and build spec, main bearing dowels and redesigned camshaft, by serial number.
4. See CAA GR24 for requirements relating to crankshaft nose, suphinuz treatment and mods 2385, 2690 and 2495 see also AD 1768 Pre 80
5. Only serial numbers after 771 are eligible for the 2000 hour TBO
6. Only serial numbers after 119 are eligible for the 2000 hour TBO
7. Only serial numbers after 4152.666 are eligible for 1200 hour TBO
   Only serial numbers after 4404.717 are eligible for 1500 hour TBO
   Refer to bulletin above for other bulletins that must be complied with for extension to 1200/1500 hours
8. Only serial numbers after 4427.532 are eligible for 1500 hour TBO
   Refer to bulletin above for other bulletins that must be complied with for extension to 1500 hours
9. Only serial numbers after 4418.103 are eligible for 1200 hour TBO
   Refer to bulletin above for other bulletins that must be complied with for extension to 1200 hours
10. For Hewland engine, LAA does not at this time approve any extension beyond 700 hours.
11. Top overhaul essential with Jabiru engines at 1000 hours.

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Figure 2 – Example Filled-in Engine Condition Monitoring Sheet

Record of condition of engine type: Continental C90-8F

Engine serial number: 3A569

Installed in aircraft: Jodel D117 G-ABBK

Last overhaul: 1968 H+S Ltd

Recommended TBO: 1800 hrs/12 years

--------------------- Results ------------------------

Parameter/year	2006	2007	2008	2009	2010	2011	2012
Engine hours	1588	1703	1820	1978	2296	2575	
Max static rpm	2100	2100	2075	2100	2100	2050	
Rate of climb at MTWA	575 fpm	600 fpm	570 fpm	620 fpm	590 fpm	500 fpm	
oil pressure at 2000 rpm and 80 deg C	40 psi	40 psi	39 psi	38 psi	35 psi	30 psi	
Oil consumption	0.25 ltr/hr	0.25 ltr/hr	0.25 ltr/hr	0.35 ltr/hr	0.5 ltr/hr	1 ltr/hr	
Compression cyl #1	76/80	75/80	76/80	75/80	70/80	65/80	
Compression cyl #2	77/80	76/80	75/80	77/80	75/80	60/80	
Compression cyl #3	78/80	76/80	77/80	78/80	74/80	65/80	
Compression cyl #4	75/80	76/80	75/80	76/80	74/80	65/80	
Appearance of paper oil filter	clear	clear	clear	Clear	small debris	metal part-icles	

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Figure 2 - continued

History of Ancilliaries

Magneto L	*Slick 4002, supplied new 2008 at 1820 engine hours*
Magneto R	*Slick 4003, overhauled 2008 at 1820 engine hours*
Governor	*N/A*
Carburettor	*Marvel-Schebler, overhauled 2007 at 1703 engine hours*
Injectors	*N/A*
Fuel pump	*AC type, new replacement 2006 at 1588 engine hours*

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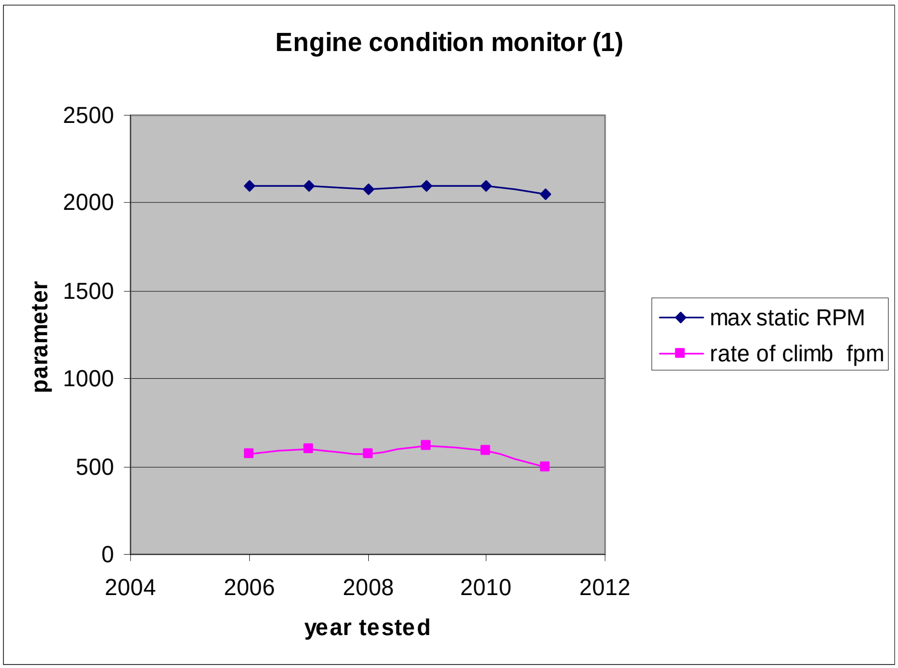
Figure 3 – typical graphical presentation of condition monitoring results



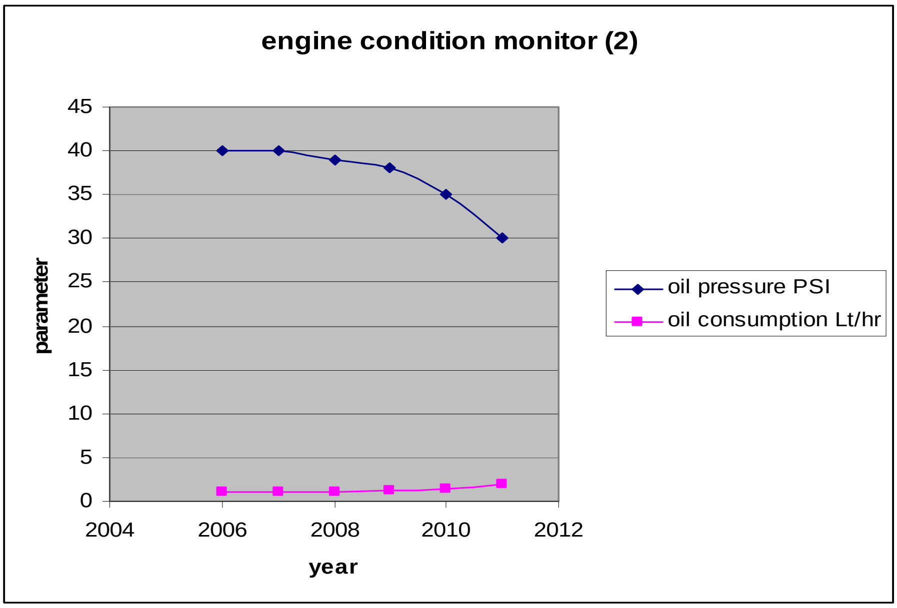


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Figure 4 – Engine Condition Monitoring Sheet

Record of condition of engine type:

Engine serial number:

Installed in aircraft:

Last overhaul:

Recommended TBO:

--------------------- Results ------------------------

Parameter/year							

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History of Ancilliaries

Magneto L
Magneto R
Governor
Carburettor
Injectors
Fuel pump

NB: suggested monitoring parameters include:

- max static RPM
- Rate of climb at MTWA, best climb speed
- oil pressure at particular cruise RPM and oil temp
- hot oil pressure at idle
- oil consumption
- compression in each cylinder
- appearance of spread-out full-flow oil filter element
- appearance of magnetic plug
- for pump-fed engines, fuel pressure at a particular RPM
- for two-strokes, big end/small end wear test result
- With VP props, airspeed at a given RPM and manifold pressure
- With Cirrus and Gipsy engines, a measure of magneto drive train backlash by a crude measure such as estimated movement at the visible surface of the Simms coupling
- With engines with manual tappet adjustment (eg VW and early Jabiru), number of 'flats' of adjustment needed to restore correct valve clearance

Note – many of these trends will be upset by any change in propeller type or fitment of the engine in a different airframe. Effective conditioning monitoring 'through' such major changes is very difficult or impossible.