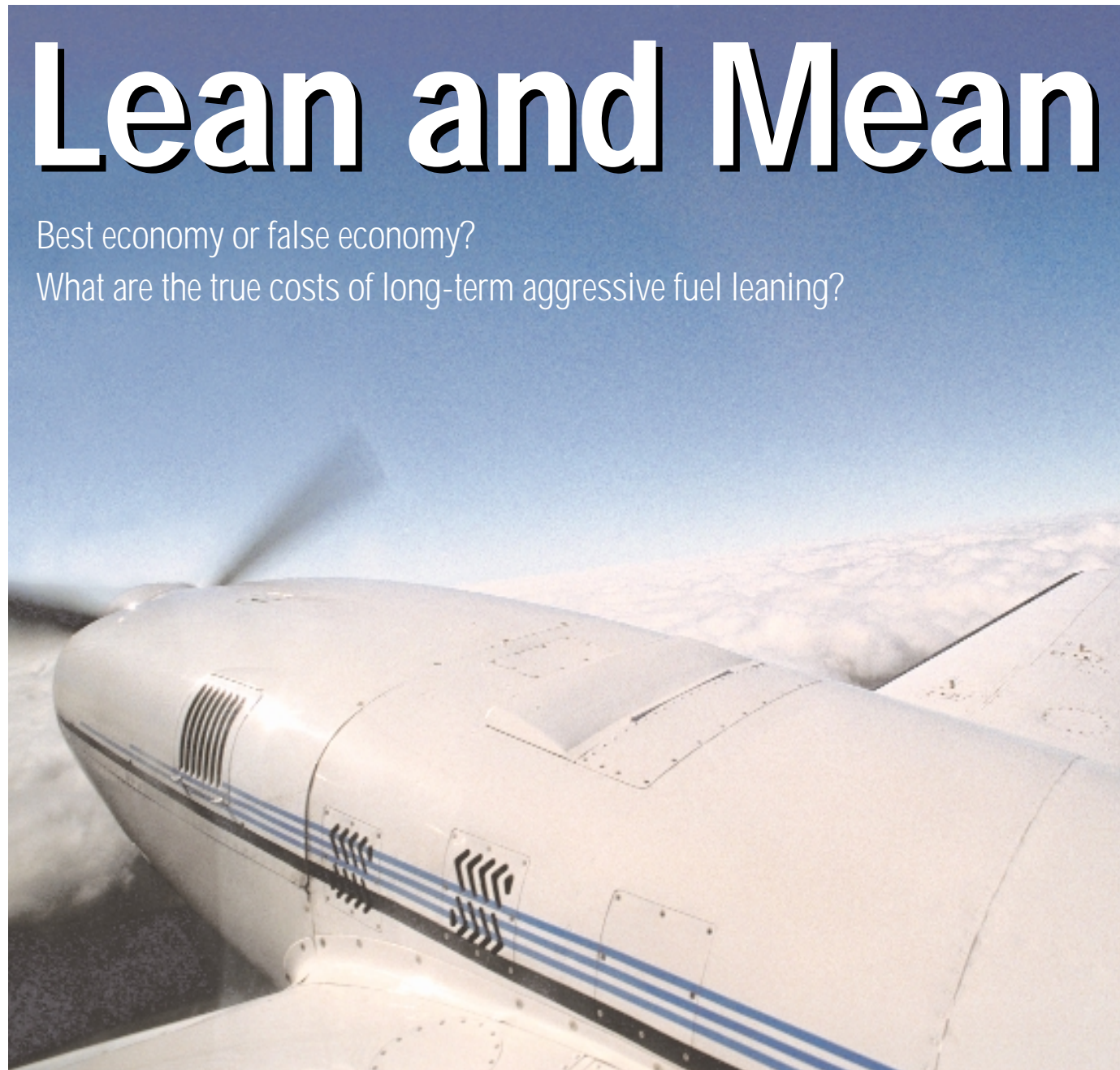


# Lean and Mean

Best economy or false economy?

What are the true costs of long-term aggressive fuel leaning?



## Staff writers

**B**ACK IN THE early seventies, the owners of two aeroplanes, one single and one twin engine, from different airframe manufacturers and with different engine brands, got talking about disappointing problems they had experienced with their new aircraft. Both had carefully studied and followed airframe and engine manufacturer's operating recommendations, and both were confident their engine handling had been by the book. Yet both owners had experienced engine defects of various kinds, unacceptably early in the service lives of their aircraft.

It was only a couple of casual remarks in a

hangar lunch room that prompted a ring-around between a handful of licensed aircraft maintenance engineers who were all known to one another. A little detective work and further examination of at least six new single and twin-engine aeroplanes, identified that they all had at least two things in common.

First, each had suffered various forms of "induced damage", including low compression, loss of power, burnt pistons, cracked cylinders, "tuliped" inlet valves and metal contamination which was later identified as con-rod bearing failure. Some even had complete engine failures. The defects were all consistent with aggressive fuel leaning and the resulting high

temperatures and pressures induced by detonation.

Second, each of the affected aircraft had been ferried across the Pacific by the same provider of ferry services.

**Detonation:** By definition, detonation is the uncontrolled explosion of the fuel/air mixture, as distinct from an even and progressive burning. Detonation occurs in a piston engine when the anti-knock rating of the fuel is lower than required by the pressure and temperature generated during engine operation. There are a number of factors which combine to create detonation. Using a fuel with an octane number (anti-knock rating) less than that required for





Before and after:  
A typical example of  
damage to a piston  
caused by detonation.

the engine is the most obvious. However, more common is over-leaning of the fuel/air mixture.

Leaning the mixture lowers the anti-knock rating of the fuel. Most high performance engines require full rich during high power settings such as take-off and climb. The reason? To ensure the fuel anti-knock rating is appropriate for the combustion pressure and temperature being developed at the high power setting. Conversely, an engine may be leaned when operating at low power settings when the temperature and pressure is less severe. It is the level of leaning which requires caution.

**Aggressive leaning:** Aggressive leaning is adjusting the fuel/air mixture to the lean side of peak EGT. Aggressive leaning reduces the fuel anti-knock rating to a level where the engine is susceptible to detonation. That is, the margin between normal combustion and detonation is minimal.

When running lean of peak, a defect such as a defective spark plug, partially blocked fuel injector nozzle or intake manifold air leak, combined with the now low anti-knock rating, provides the recipe for destructive detonation, and engine damage is inevitable. The defective spark plug, fuel nozzle etc, is not the real issue of concern, it is the deliberate reduction of the available detonation margin by aggressive leaning.

Detonation resulting from aggressive fuel leaning can be a subtle cause of engine damage. Detonation can result in combustion pressures and temperatures exceeding the capacity of the

connecting rod bearings and the material temperature limit of the piston. Excessive combustion temperatures and operating pressure are among the most destructive things that can happen to any piston (or turbine) engine, and the induced failure may occur long after the initial damage has been inflicted. While detonation in a piston

engine induced through aggressive leaning is not the only inadvertent abuse a pilot can inflict on a powerplant, it is one of the most frequent and avoidable.

**The pilot:** In the general aviation environment, it's common for individual aircraft to be operated by a large number of different pilots. This makes it imperative that all pilots and operators understand and implement the principles of fuel/air mixture leaning, because one single event, although the pilot may never be identified, can sow the seed for a future catastrophic engine failure.

**Extra care:** Whilst all piston engines are inherently prone to such damage if proper care is not taken, the potential for detonation events, and the cost of the resulting damage, increases with the power rating of the engine; and it is therefore the more sophisticated, complex engines which are the most exposed. Examples of engines which require extra care are:

- Geared propeller, turbocharged engines such as the Teledyne Continental Motors GTSIO-520 series which power aircraft such as the Cessna 421.
- Geared supercharged engines such as the

Textron Lycoming IGS0-540 (Beechcraft Queen Air B80).

- Turbocharged engines such as the Textron Lycoming TI0-540 series (Piper Chieftains).

**Ageing aircraft:** For most of the still popular ageing aircraft types, it is possible to buy a brand-new engine. Engine manufacturers can also supply a zero time, remanufactured (or "reman") engine by rebuilding a time expired engine to new part dimensions. A reman engine effectively provides an operator with a completely new engine.

Overhauling a time-expired engine returns the engine to a standard where that engine is again capable of achieving a further service life. Therefore, while engine failures do occur in ageing aircraft, the failures should not just be attributed to the aircraft's age. Regardless of the aircraft's age, improper pilot operating procedures (in particular, aggressive leaning), plays a major role in inducing engine failure.

**Good and bad reading:** Ample literature is available from engine manufacturers on engine handling, including leaning and most of this information is applicable to a wide range of engine makes and models. Textron Lycoming's "Key Reprints from Lycoming Flyer" and Teledyne Continental Motors' (TCM) "Tips on Engine Care" are excellent publications and available free on request to all owners and pilots from most Lycoming and TCM distributors. It is important that all owners and pilots seek out such information and absorb it.

However, caution is advised when reading articles written by well-meaning enthusiasts. A recent internet article promoting lean of peak mixture leaning, whilst extremely well researched and written, did result in hair pulling responses by engineers and engine manufacturers. The lesson is to compare the advice given in the article with that published by the engine manufacturer. When in doubt, balance the engine manufacturer's qualifications against the author's.

**Pre-ignition:** The presence of a static hot spot in a cylinder, such as a carbon lump or cracked spark plug ceramic, can lead to pre-ignition. A static hot spot and aggressive leaning can lead to pre-ignition detonation, which almost always results in destructive detonation. Detonation may destroy a piston or con-rod bearing before the pilot can react, even if the pilot could detect the damage occurring. Again, the destruction is avoidable. The static hot spot is a minor defect, but aggressive leaning turns it into induced destructive detonation.

**Fuel/air mixture distribution:** While an engine manufacturer may strive for an equal fuel/air mixture between individual cylinders of an engine, this ideal situation is rarely reached. The Piper Malibu is one of very few aircraft which has an engine with near perfect fuel/air distribution, and is therefore one of the few aircraft types approved by the engine manufacturer to run mixtures lean of peak. So for most aircraft, variations between cylinders should be one of the prime considerations when leaning the fuel/air mixture. As most pilots have little idea of which cylinder is the leanest, the leaning procedure should be conservative. That is: lean to the rich side of peak.

**Temperature indication:** Aggressive mixture leaning will result in an observed decrease in cylinder head temperature (CHT) or exhaust gas temperature (EGT).

(Note: some turbocharged engines use turbine inlet temperature (TIT) in lieu of EGT.) A decrease in CHT and EGT suggests aggressive leaning aids engine cooling and is therefore beneficial to the engine, in particular the cylinders. Not so. The lean mixture is burning so slowly, the peak temperature is occurring during the exhaust stroke in the exhaust port where it cools quickly.

Backfiring through the carburettor is the result of a lean mixture still burning when the inlet valve opens during the exhaust stroke overlap. The temperature of the slow burning mixture can exceed the material limit of the inlet valve resulting in the deformation of the valve head known as tuliping. Therefore, what the pilot is seeing on the CHT/EGT gauge when aggressively leaning is not necessarily a good thing.

**EGT versus CHT:** An EGT probe responds to gas flow temperature, while a CHT probe responds to cylinder head material temperature. A power or mixture change soon becomes apparent on an EGT probe. A CHT probe only indicates the metal temperature at the site of the probe. This may not be the hottest part of the cylinder head, let alone the hottest cylinder on a single CHT probe engine. However, owners and pilots should note; engine manufacturers do not approve the use of EGT probes on individual cylinders when leaning the

fuel/air mixture.

**Instrumentation calibration:** Of importance, when leaning to an indicated EGT or TIT; the effectiveness of engine mixture leaning is dependent on the accuracy of the temperature probe and gauge. An under-reading EGT probe invites operating the engine beyond the manufacturer's temperature limits with a resultant deterioration of the engine condition. Therefore, money saved in not maintaining the engine temperature instrumentation is well and truly lost to higher overhaul costs. Manufacturers recommend the relevant instruments, EGT or TIT be calibrated annually to ensure their accuracy.

**Economics:** The long-term benefits of conservative fuel leaning procedures should not be overlooked. Both Textron Lycoming and Teledyne Continental

**Both Textron Lycoming and Teledyne Continental report that engines which have been subjected to aggressive leaning rarely make published TBO.**

report that engines which have been subjected to aggressive leaning rarely make published TBO. At the overhaul, engines subjected to aggressive leaning require more detailed work and the replacement of expensive components not usually associated with a normal overhaul. The savings in fuel

costs over the average engine TBO period should then be weighed against the cost of a premature overhaul. A short term gain may not be the cheapest option.

**When to lean:** Most manufacturers recommend that fuel/air mixture leaning not be carried out above normal cruise power, and in almost all situations they recommend that take-off and initial climb be at full-rich mixture. It is important to remember that any change on engine power is likely to require a mixture readjustment; so that mixture should normally be moved to the rich side to avoid over-leaning until a power change is completed and stabilised.

**Leaning procedures, which is best?** There are many experts on this subject. Some are professionals, some are well-meaning enthusiasts. Their views often conflict, and it is important to understand where each is coming from. There is also conflicting data published on this subject by the manufacturers themselves. Fuel leaning procedures published by some aircraft manufacturers include aggressive leaning contrary to the engine manufacturer's

## Wait for it...



Philip Smith

**W**HEN LEANING, it is important to remember that the exhaust gas temperature (EGT), cylinder head temperature (CHT) and turbine inlet temperature (TIT) gauges do not reflect temperature changes instantaneously.

For this reason, always lean the mixture incrementally and allow several seconds for the EGT gauge to indicate a change. If you do not lean slowly and allow sufficient time for the instrument to "catch up", it is very easy to miss peak EGT, or other important indications, and end up leaning to the wrong figures.

One technique is to reduce the mixture by a set fuel-flow, say by a one-gallon-per-hour increment (choose a figure suitable for your aircraft type), then wait several seconds for the gauge to move and stabilise. Repeat the process until peak EGT is determined.

This technique guarantees consistency and reduces the chances of leaning to a mixture not approved in either the Pilot's Operating Handbook (POH) or the standard operating procedures (SOPs).

*Philip Smith is an aviation consultant who specialises in operating techniques for light twin-engine aircraft.*





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published recommendations.

So how do aircraft owners and pilots decide which leaning procedure is best for them? Which manufacturer is ensuring the engine can reliably achieve its published service life? Which manufacturer is marketing aircraft range performance? The answer is obvious.

The following Textron Lycoming leaning procedure for Lycoming turbocharged engines is an example of the issues that must be considered when adjusting the fuel/air mixture:

1. The cylinder head temperature (CHT) and turbine inlet temperature (TIT) gauges are required instruments for leaning with turbocharging by Textron Lycoming. EGT probes on individual cylinders should not be used for leaning.
2. During manual leaning, the maximum allowable TIT for a particular engine must not be exceeded. Check the POH/AFM or the Textron Lycoming Operator's Manual to determine these temperatures and fuel flow limits.
3. Maintaining engine temperature limits may require adjustments to fuel flow, cowl flaps, or airspeed for cooling.
4. All normal take-offs, with turbocharged powerplants, must be at full rich mixture regardless of airport elevation.
5. If manual leaning of the mixture is permitted at take-off, climb power, or high performance cruise, it will be specified in the POH/AFM and will list required ranges for fuel flow, power settings, and temperature limitations.

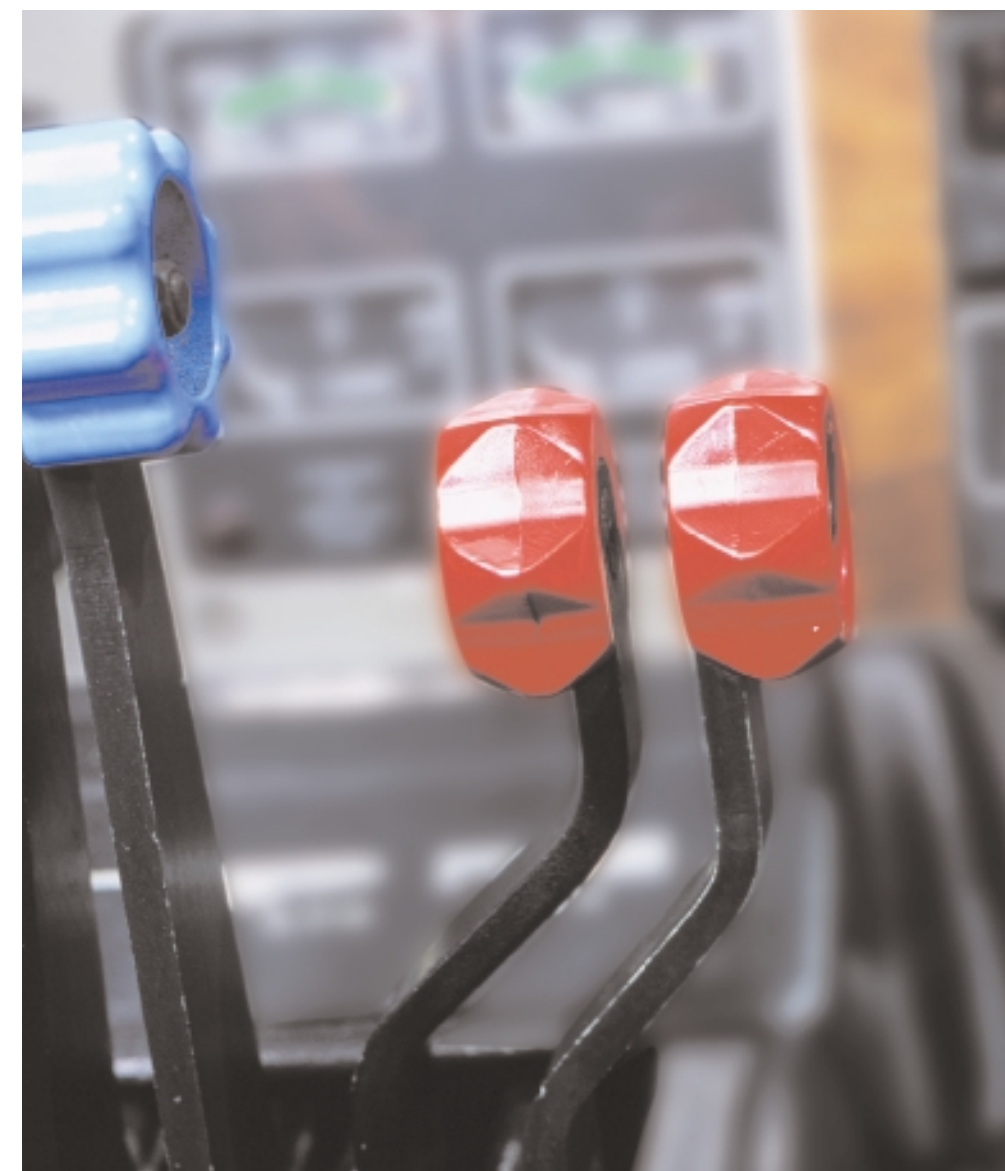
Leaning to best economy mixture:

- (a) Set manifold pressure and RPM for the desired cruise power setting per the aircraft's POH/AFM.
- (b) Lean slowly in small steps, while monitoring instrumentation, to peak TIT or maximum allowable TIT, whichever occurs first.

Note: Lycoming does not recommend leaning to lean of peak.

Leaning to best power mixture: Before leaning to best power mixture, it is necessary to establish a TIT reference point. This is accomplished as follows:

- (a) Set manifold pressure and RPM for the highest cruise power setting where leaning to best economy is permitted per the aircraft POH/AFM.
- (b) Lean slowly in small steps until peak TIT or maximum allowable is reached. Record peak TIT as a reference point.
- (c) Deduct 125°F from this reference and thus establish the TIT temperature for best power mixture operation.
- (d) Return the mixture to full rich and adjust manifold pressure and RPM for the desired cruise conditions.
- (e) Lean mixture to the TIT temperature for best



Too lean: While it is possible to achieve lower fuel consumption through aggressive leaning, in practice the short-term savings will almost always be outweighed by the cost of a premature overhaul.

power mixture operation established in step (c). (f) During normal operation, maintain the engine power settings; cylinder head temperature limit; oil temperature limits and turbine inlet temperature limit listed in the Textron Lycoming Operator's Manual.

**The final word:** Unless otherwise approved, The Civil Aviation Safety Authority requires aircraft be operated in accordance with the instructions provided by the aircraft manufacturer. However, there are often sound reasons to be more conservative than what is permitted by the manufacturer, and to avoid aggressive leaning.

While it is possible to achieve lower fuel consumption by leaning beyond peak EGT, in practice there are other factors beyond the

pilot's control which may impact on the engine's general well being. Thus, aggressive leaning is strongly discouraged. The saving in fuel is more than outweighed by engine overhaul cost and the potential for major engine damage which detonation may cause. For a further understanding of the significance of this issue refer to the article "Chieftain investigation leads to safety recommendations" (*Flight Safety Australia*, November/December 2000, p. 51).