

# Turbo Talk: Temperature, Temperature, Temperature

*Those three words hold the secret to making your aircraft engine operate trouble-free for a long time.*

*March 19, 2009—Mike Busch <mike.busch@savvyaviator.com>*

## **My quest for the secret of engine longevity**

**In 41 years as an aircraft owner, I've owned three aircraft (two singles and a twin), all powered by big-bore TCM engines.**

My engines have never failed to make TBO with minimal maintenance along the way.

In recent years, they've gone well beyond TBO. Both engines on my TSIO-520-powered twin are now 1,150 hours past TBO and still going strong.

**For decades, I was convinced that the secret of my success was the fact that I “babied” my engines, limiting cruise power to 60% or 65%.**

**More recently, I've come to learn that this is wrong.**

Babying the engine (reduced power) is one way to achieve long engine life, but it's not the only way.

It's not power that damages our engines—it's temperature. You can run these engines just as hard as you like so long as you keep temperature under control.

Or as powerplant guru and former TCM field rep Bob Moseley says: “There are three things that affect how long your engine will last: (1) temperature, (2) temperature, and (3) temperature.”

*(Most of what I've learned about this subject has come from my old friends George Braly of GAMI and Bob Moseley of SkyTEK, both of whom have forgotten more than I'll ever know about piston aircraft engines. George has done more research on piston aircraft engine operation than anyone on the planet, and is singlehandedly responsible for rewriting the book on how these engines should be operated. “Mose” has more real-world experience in diagnosing and solving engine problems than anyone I know.)*

## **It's all about the heat**

### **Our piston aircraft engines are heat engines.**

They have moving parts—notably exhaust valves and valve guides—that are continually exposed to extremely high temperatures in the 1,200°F to 1,600°F range (and sometimes even hotter).

Since engine oil cannot survive temperatures above about 400°F, these moving parts must function with no lubrication. They depend on extremely hard metals operating at extremely close tolerances at extremely high temperatures with no lubrication.

It's nothing short of miraculous, and a testament to outstanding engineering, that they last as long as they do.

### **The key to making these critical parts last is temperature control.**

The most important temperature is cylinder head temperature (CHT).

Bob Moseley (who has been overhauling these engines for nearly four decades) says that an engine that is operated at CHTs above 400°F on a regular basis will show up to five times as much wear metal in oil analysis as an identical engine that is consistently limited to CHTs of 350°F or less.

“It's amazing how much a small increase in CHT can accelerate engine wear,” says Mose.

### **As critical as CHT is, many owners don't have a clue whether their CHTs are over 400°F or less than 350°F.**

That's because they rely on pathetically inadequate factory engine instrumentation.

The factory CHT gauge looks at only one cylinder, and it's not necessarily the hottest one.

Further, the green arc on the factory gauge extends up to a ridiculously hot 460°F.

If all you have is a factory CHT gauge, you could easily be cooking your valves to death while blissfully thinking that all is okay because the CHT is in the green.

To know what's really going on in front of the firewall, you have to have a modern multi-probe engine analyzer with a digital readout.

Such instrumentation isn't cheap—figure \$2,500 for a single or \$5,000 for a twin, installed.

If it saves you from having to replace a couple of jugs en route to TBO, it has more than paid for itself.

With the exception of your annual ABS dues, installing a digital engine analyzer is probably the best money you can spend on your airplane.

## **Focus on CHT, not EGT**

### **Our piston aircraft engines are very inefficient.**

They convert only about one-third of the latent energy contained in 100LL into useful energy that drives the propeller and produces thrust.

About half the fuel's energy goes out the exhaust pipe. (A turbo recaptures some of that.)

The remaining one-sixth is transferred to cooling air via the cylinder fins and oil cooler.

### **This energy—useful and wasted—is displayed on cockpit gauges.**

Wasted energy that goes out the exhaust pipe is displayed as EGT and TIT.

Wasted energy that is transferred to cooling air is displayed as CHT and oil temperature.

Useful energy that drives the prop is displayed as airspeed.

### **CHT and EGT tell us quite different things.**

CHT mainly measure heat energy wasted during the power stroke, when the cylinder is under maximum stress from high internal pressures and temperatures.

EGT measures heat energy wasted during the exhaust stroke, when the cylinder is under relatively low stress.

High CHT generally indicates that the cylinder is under excessive stress.

High EGT does not indicate that the cylinder is under excessive stress, only that a lot of energy from the fuel is being wasted out the exhaust (rather than being extracted as useful mechanical energy that drives the propeller).

High EGT often correlates with low cylinder stress:

A low-compression engine always has higher EGTs because it extracts less energy from the fuel, so more goes out the tailpipe.

A non-firing spark plug always increases EGT because the combustion event takes longer and so less energy is extracted and more is wasted out the tailpipe.

EGT is not a “real temperature.”

The exhaust valve is closed two thirds of the time, so the EGT probe sees nothing.

When the exhaust valve opens, the exhaust gas that flows past the EGT probe starts out quite hot and continuously cools as the exhaust stroke progresses.

The EGT probe tries to integrate this constantly changing series of temperatures into the value we see on the EGT gauge. It's not an actual gas temperature—it's a weird average of constantly changing gas temperatures.

For this reason, the absolute value of EGT (e.g., 1390°F) isn't particularly important. Only the relative value is important (e.g., 100°F ROP, 40°F LOP).

Bottom line on CHT and EGT:

Limiting CHT is absolutely essential to ensure optimum cylinder longevity.

Limiting EGT accomplishes nothing useful. (There is no such thing as an EGT red line.)

## **Fuel system setup**

**Takeoff and initial climb are performed at wide-open throttle, full-rich mixture, maximum RPM, and wide-open cowl flaps (if we have them).**

There's not much we can do from the cockpit to affect CHT (other than airspeed control).

The primary determinant of CHT is how our full-power fuel flows are adjusted.

**It is shockingly common to see damagingly high CHTs (well above 400°F) due to improperly adjusted fuel flows.**

It is not unusual for the fuel flows to be set wrong from the day an engine is installed, and never to be checked or adjusted all the way to TBO.

The owner winds up going through cylinders every 500 hours and never knowing why (or blaming the manufacturer).

Much of the problem lies with mechanics who don't fully understand how critical it is to test and adjust the fuel system setup on a regular basis.

Most shops don't even have the necessary test equipment to adjust the fuel flows properly.

Even when mechanics do test and adjust the fuel system, they often adjust it wrong.

TCM SID97-3 contains a lengthy table that specifies full-power fuel flow as a range (minimum and maximum). Many mechanics adjust it to the middle of the range.

However, the text of SID97-3 instructs mechanics to adjust the full-power fuel flow to the high end of the specified range.

Aftermarket engine modifications can complicate this issue.

Millennium cylinders breathe more air than factory jugs (due to greater volumetric efficiency), so they need higher fuel flow, otherwise they run hot.

Aftermarket intercoolers cause the engine to breathe cooler, denser air, so they need higher fuel flow to maintain proper mixture.

Many A&Ps refuse to adjust fuel flow above the max specified in TCM SID97-3, ignoring the fact that TCM specifically states that TCM SID97-3 does not apply to engines that have been modified with non-TCM components.

**Do you have enough fuel flow?**

A quick-and-dirty rule of thumb for turbocharged engines is that your takeoff fuel flow should be at least 10% of your maximum rated horsepower.

E.g., a 285 hp engine should flow at least 28.5 gph, and a 310 hp engine should flow at least 31.0 gph.

For a turbonormalized engine (8.5-to-1 compression ratio), the flow should be somewhat less.

CHT during takeoff and initial climb should not exceed about 380°F.

It's even better if they're around 350°F.

Some recommend that EGTs should not exceed about 1400°F, but I consider this number far less important than CHT and fuel flow.

## **Cruise control**

**Cruise flight represents the lion's share of our flying time, so temperature control in cruise is especially important.**

Just as with takeoff and climb, it's essential to keep all our CHTs at or below 380°F during cruise to achieve good cylinder longevity, and 350°F is even better.

**There are three alternative strategies for keeping CHT under control during cruise flight:**

**Cruise at reduced power ("baby the engine")**

**Cruise at a very rich mixture (100°F ROP or more)**

**Cruise lean-of-peak (20°F LOP or more)**

**All three strategies can result in good longevity with minimum cylinder problems, but each has its pros and cons:**

### Reduced power (65% or less)

Pro: You can set the mixture anywhere you like without risk of damage, even peak EGT or 50°ROP.

Con: Reduced airspeed.

Since airspeed varies with the square-root of power, reducing from 75% to 60% (a 20% power reduction) results in an airspeed loss of about 11% (~19 knots in a B36TC).

### Very rich mixture

Pro: Maximum airspeed.

Con: Poor fuel economy.

Max CHT occurs ~50°ROP

Reducing CHT by 25°F requires richening to ~160°F ROP, a fuel flow increase of at least 3 gph.

If 100LL costs \$4/gallon, this adds \$12/hour to cost.

Range and payload is also reduced.

Con: Dirty combustion.

Very rich mixtures result in increased deposits on exhaust valves, spark plugs, cylinder heads and piston crowns.

These deposits are likely to cause more frequent exhaust valve and ignition problems, necessitating additional maintenance expense.

### Lean-of-peak

Pro: Optimal fuel economy.

Max CHT occurs at ~50°ROP.

Reducing CHT by 25°F requires leaning to ~10°F LOP, a fuel flow reduction of ~2 gph.

Reducing CHT by 45°F requires leaning to ~40°F LOP, a fuel flow reduction of ~3 gph.

Pro: Clean combustion.

Inspecting a cylinder using a borescope, the difference between an engine operated ROP and one operated LOP is very striking. The LOP cylinder and piston are clean as a whistle, while the ROP cylinder and piston have heavy deposit buildup.

Con: Reduced airspeed?

Leaning from 50°F ROP to 10°F LOP reduces horsepower by ~3% and airspeed by less than 2%.

Leaning from 50°F ROP to 40°F LOP reduces horsepower by ~6.5% and airspeed by less than 3.5%.

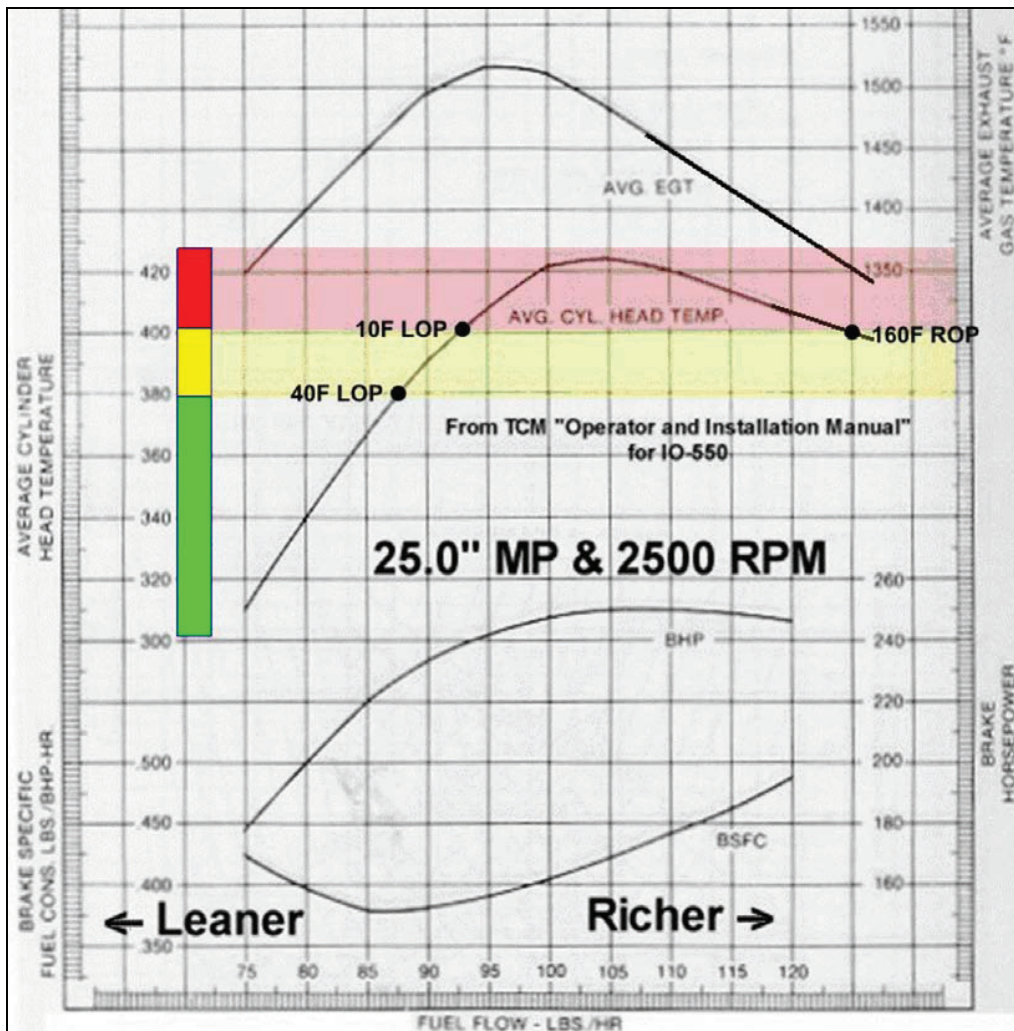
In a turbo, you can usually increase MP to eliminate this airspeed loss.

Con: Engine must have even mixture distribution

TCM crossflow engines generally run well LOP right out of the crate.

TCM bottom-induction engines usually need position-tuned fuel injector nozzles (either TCM or GAMInjectors) to operate LOP without unacceptable roughness.

Certain engines (notably the TSIO-520-UB) have unusually uneven mixture distribution, and often cannot be operated more than slightly LOP.



## **Keep your cool!**

**Whatever strategy you prefer, the important thing is to keep a close watch on your CHTs and ensure that they remain cool.**

The best way to do this is to install a multiprobe digital engine monitor and program its CHT alarm to go off at 390°F or 400°F.

Not the default, which is much higher.

If the alarm goes off during takeoff or initial climb, you're going to have to get your mechanic to turn up the full-power fuel flow.

If the alarm goes off during cruise, either richen (if ROP) or lean (if LOP) to bring the CHT down to acceptable levels.

**If you don't have a multi-probe digital engine monitor, install one.**

The cost of such instrumentation (including installation) is usually about the cost of replacing one cylinder.

It'll probably pay for itself in 500 hours or less.

## **Questions?**