All About EGT & CHT

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CHT, EGT, TIT, detonation, pre-ignition: what do they really mean?

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Extracted from a YouTube video: https://www.youtube.com/watch?v=fqe9j74qMdk
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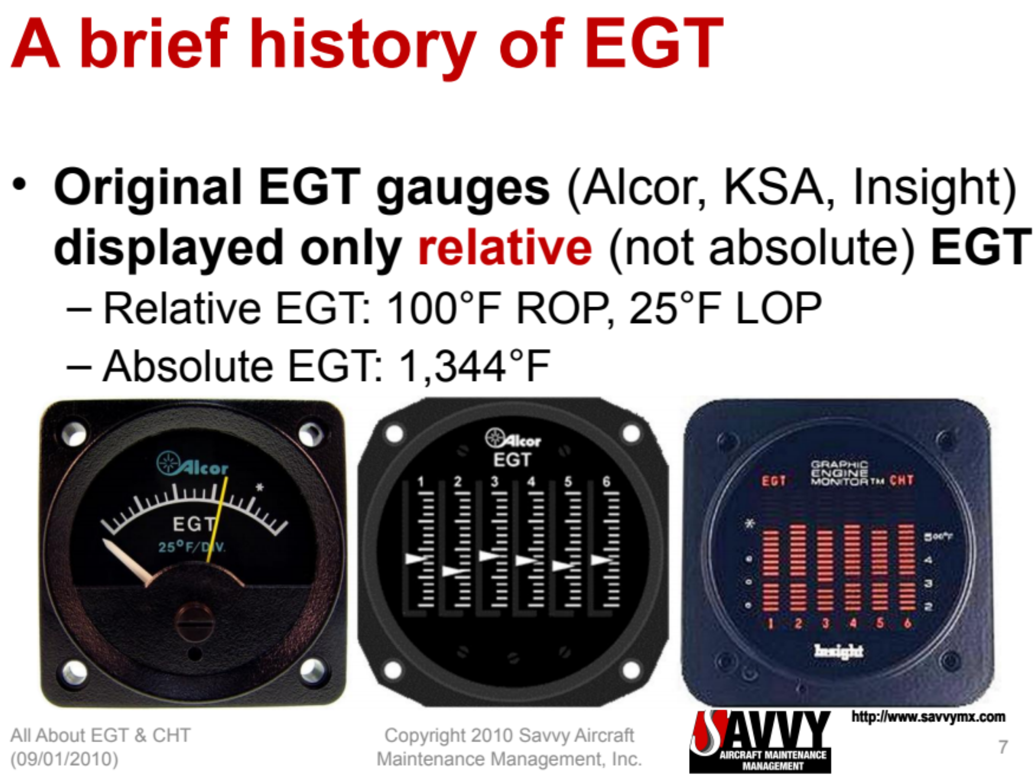
Text summarized and reworded for easier reading.
Savvy Aviation YouTube channel: https://www.youtube.com/channel/UCc-IpamUhzvGsAfMzH2IIcA/videos

EGT & CHT: lots to discuss…

- **A brief history of EGT**—the theory of relativity
- **Ignore absolute EGT**—it's not a real temperature
- **What EGT & CHT really mean**—wasted energy
- **The flat-top myth**—GAMI spread vs. EGT DIFF
- **Troubleshooting tips**—where EGT really shines
- **Detonation**—when combustion press/temp is too high
- **Pre-ignition**—when combustion begins too early
- **Managing CHT**—how mixture affects CHT



Original EGT gauges (Alcor,KSA, Insight) displayed only relative (not absolute) EGT:

- Relative EGT: 100 ºF ROP, 25 ºF LOP
- Absolute EGT: 1,344 ºF

One of the first EGT instruments appeared in the 60s, manufactured by Alcor.
The company was owned by a petroleum engineer by the name of Al Hundere.
https://alcorinc.com/index.php/history/

The original EGT indicators were very simple. They were a little steam gauge connected to a single thermocouple probe located in the exhaust cluster somewhere. Note that there are no numbers on the instrument.
The instrument has a scale calibrated with tick marks, spaced in twenty-five ºF. There's a yellow reference pointer that can be manually adjusted.

Some other instruments had a fixed reference pointer - the asterisk on the dial above.
This instrument shows relative EGTs - not absolute EGTs. Realtive meaning in relation to peak EGT.
Instrument usage: lean the engine until EGT peaked; set the reference pointer at that point and then enrich until the EGT drops a certain amount from peak, those days typically 100 - 125 deg F rich of peak EGT.
But nobody had any idea what the EGT was in absolute terms.
All we had was relative information. We knew what EGT was in relationship to peak, but we didn't know what the absolute value was.

Later on, in the early 70s, engine monitors started appearing.
They were very primitive: the Alcor unit pictured is an example, and it was four or six of these analog EGT gauges, stacked up into a single instrument package.

In the 70s, Insight introduced the graphic engine monitor (GEM). Similarly, it had a display with no EGT numbers on it. There was a CHT scale on the right but the EGT scale had no numbers on it.
It was simply a relative scale and these instruments were used to lean to a peak value and then one could enrich or lean, to bring the EGT down a certain amount from peak in a manner very similar to the analog gauges.

Each segment on these digital bar graphs was worth twenty to twenty-five ºF.
The display was more sophisticated and the software had some sophiticated functions, like lean find.
When it came to EGT, the information presented was relative. This turned out to be a good thing.

A brief history of EGT

- **Trouble began when instruments started displaying absolute EGT**
  - E.I.'s US-8, then JPI's EDM-700 and E.I.'s UBG-16
  - This was a bad thing!
  - Why? Because absolute EGT is meaningless. **EGT is not real temperature!**

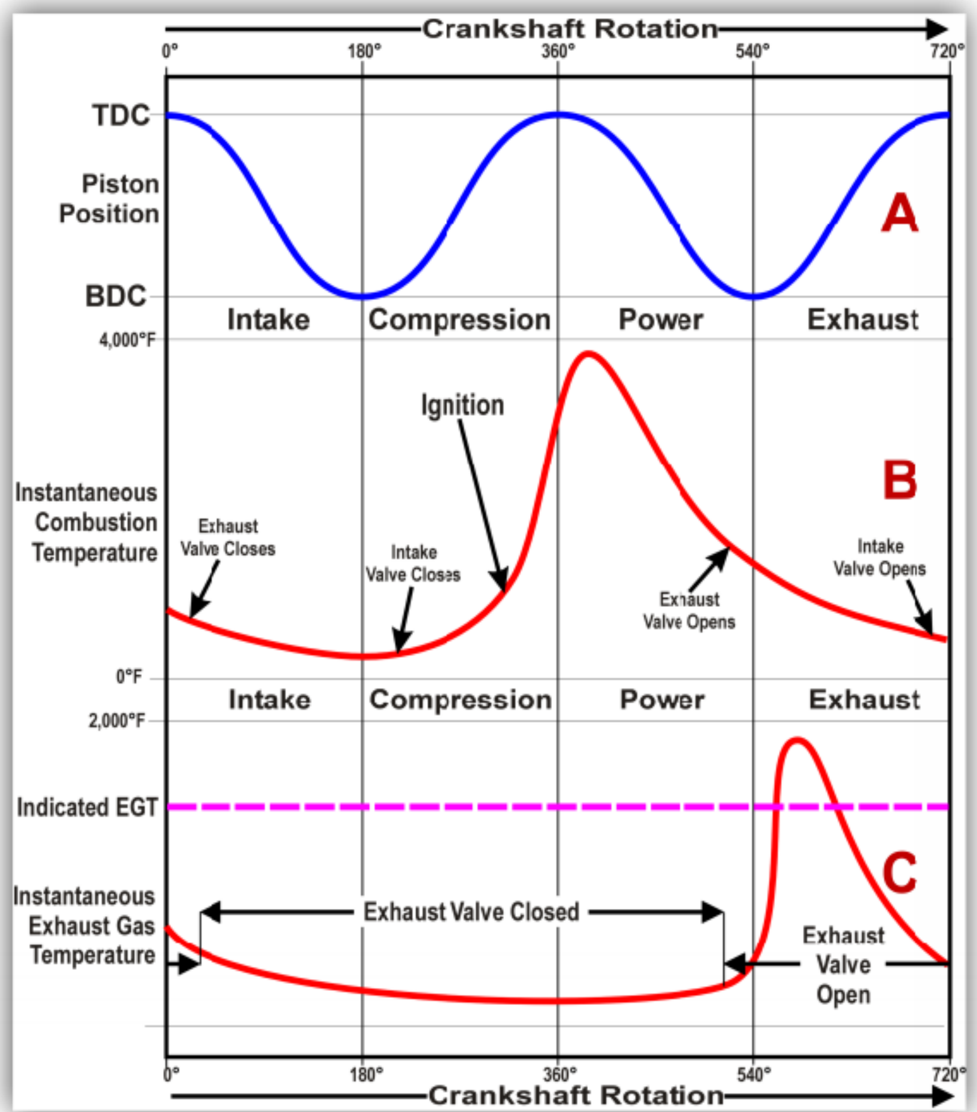
Things got a little bit messier when Electronics International introduced the US-8 (ultimate scanner eight) and for the first time CHT an EGT information was presented not as relative values but as absolute digital values.
Their marketing material was touting the fact that for the first time you could see your EGT with one degree accuracy and know exactly what it was.
It caused pilots to obsess about absolute EGT values and compare their EGTs with the EGTs of others.

A little later, a new startup company, JP Instruments, introduced what ultimately wound up being the best-selling engine monitor in history, the EDM 700. JPI combined the bar graph display that Insight had on its GEM, with the digital readout that the Electronics International had on its scanners.

Pilots started fixating on these EGT numbers and using them in all sorts of inappropriate ways. This turned out to be a major distraction, because these EGT absolute values are meaningless: EGT is not a real temperature!

Why EGT is not a real temperature

and why absolut EGT is meaningless



All About EGT & CHT (09/01/2010)

The diagram above shows two crankshaft rotation, 720 degrees. The blue line is the piston position: it starts at top dead center and ,during the intake stroke, the piston goes down to bottom dead center. Then the piston comes back up to the top dead center during the compression stroke. It then goes back to bottom dead center during the power stroke, comes back up to top dead center during the exhaust stroke.
And then the cycle process repeats.

If a temperature probe could be placed inside the combustion chamber, this is what it would show: During the intake stroke, the exhaust valve closes, the intake valve is open and the

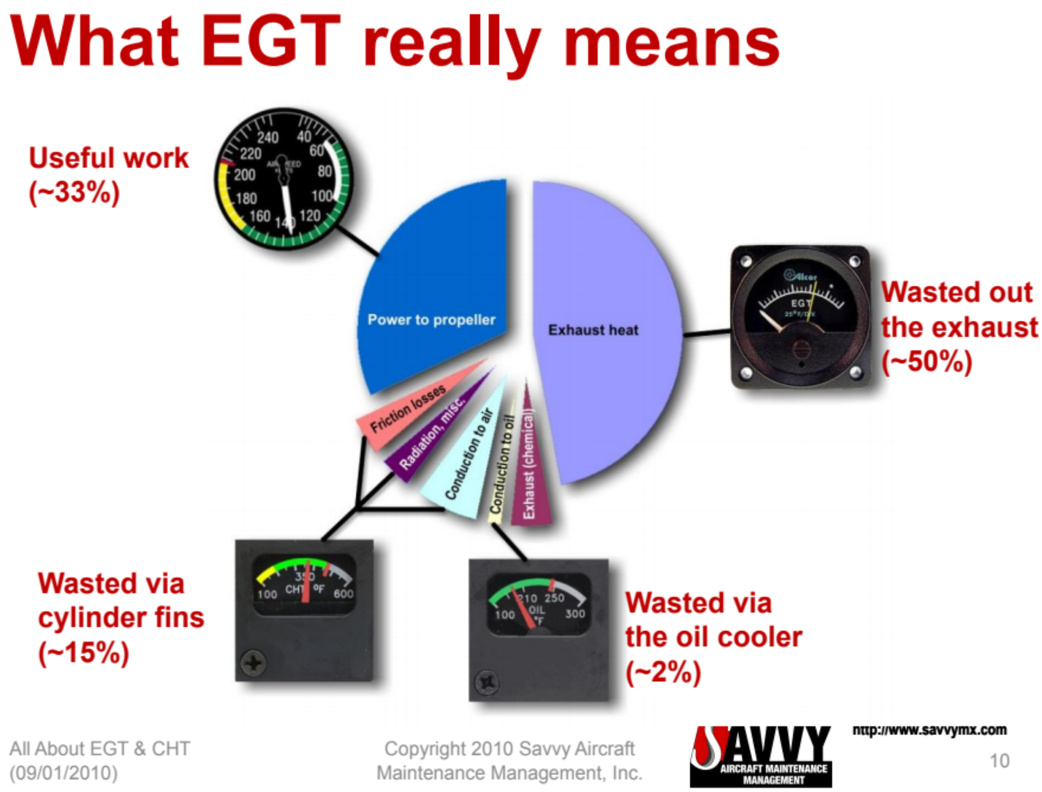
cylinder is breathing in a mixture of air and fuel. The temperature in the combustion chamber is low and it gets lower as the air/fuel mix enters the cylinder.
Then the piston starts back up, the intake valve closes and the fuel/air mixture is compressed. As it is compressed, it heats up.
The spark plug fires and this fuel/air mixture starts to combust. At that point, the temperature starts rising very rapidly, through top dead center.
It keeps rising until it reaches a peak, typically 16 degrees or so after top dead center.
This is the peak pressure point in the cycle. As the combustion continues and the piston starts moving down, the gas expands and is converted into power through the crank shaft rotation. The combustion temperature starts declining rapidly.
When the piston is almost at the bottom of the stroke, the exhaust valve opens and the piston starts heading up, ejecting this exhaust gas out the exhaust port, and when the piston is almost at top dead center the intake valve opens in preparation for the intake stroke.

There's actually a period of time where both valves are open: it is called a valve overlap period. It is a fairly short period of time, when the intake valve has started opening and the exhaust valve hasn't closed yet.

But, of course, there are no temperature probes inside the combustion chamber. There are only EGT probes.
EGT probes are mounted in the exhaust riser pipe, typically 2 to 4 inches from the exhaust valve. So during the entire period when the exhaust valve is closed, despite all the activity inside the combustion chamber, the EGT probe doesn't see any of it.

The EGT probe is not exposed to anything particularly interesting during about two-thirds of the cycle. Then, when the exhaust valve finally starts to open for the exhaust stroke, all of a sudden the EGT probe "sees" exhaust gas, which starts out very hot, but not anywhere near as hot as the peak in the combustion chamber. that is around four thousand ºF, but the probe is exposed to temperatures around 2000 ºF. But then, as the exhaust stroke continues and the pressure goes down, and gases escape from the combustion chamber, it cools down very rapidly. After the exhaust stroke is over, the exhaust valve closes and the EGT probe for the next 2/3 of the cycle sees nothing.
In short, the EGT probe sees short pulses of rapidly changing gas temperature, punctuated by long periods of nothing.

The probe, which has a fair amount of thermal mass, integrates all of these rapidly changing temperatures, settling at some equilibrium temperature, which it reports to our EGT gauge. This temperature is not a gas temperature, it is the temperature of the probe. The EGT has very little relationship to any of the combustion temperatures, because during most of the combustion process, the EGT probe is blind. This is why EGT is not a "real temperature", and the absolute value of EGT is not a particularly meaningful number.



Piston aircraft engines are remarkably inefficient at converting the latent energy in avgas into useful power. In fact, the best output of a piston engine is about one-third efficiency. Only about one third of the energy in the fuel, is converted into useful work turning the propeller. At least two-thirds, and often more than two-thirds of that energy, is wasted.

In a turbocharged engine, a little bit of the exhaust energy is captured, and used to drive a turbine. But still, about half the energy in the fuel goes out the exhaust pipe.

The next largest chunk of energy is lost to heating up the cylinders. If the cylinders were perfectly efficient, they would run cold, with all of the energy in the fuel converted into mechanical energy. But roughly fifteen percent of the energy is dissipated as heat by the cylinder.

Another small portion of that energy is wasted heating up the oil and then dissipated in a radiator.

So two-thirds of the energy is dissipated as heat and does not propell the airplane.

Cockpit instruments show the amount of energy that is wasted:

- the EGT gauge shows how much energy is being lost through the exhaust;
- the CHT gauge measures the energy being lost through heating up the cylinder;
- the oil temperature gauge shows how much of it is being wasted heating up the oil;
- the airspeed gauge indicates how much is being turned into useful work. It doesn't show the power directly, but the airspeed is proportional to the square root of the power output of the engine.

What EGT really means

- **CHT** measures 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 exhaust valve is open and the cylinder is under relatively low pressure, temperature and stress.

The CHT gauge measures the energy that is being wasted during the power stroke, when the combustion temperatures and pressures are at their highest. Both valves are closed and the cylinder is under maximum stress.

CHT shows how much stress the cylinder is under. It is not measuring it directly in pounds per square inch, but CHT is the best proxy that we have.
Its reading is representative of the stress the cylinder is under and the energy that generates CHT: During the power stroke the cylinder, piston, connecting rod, etc. are under maximum stress, as that is when pressures and temperatures are highest.

EGT, on the other hand, measures heat energy that is wasted during the exhaust stroke, as that is the only time when the EGT gauge actually "sees" anything. It measures the energy wasted by dumping hot combustion gases out the exhaust port, after the engine has extracted as much energy as it could.
The EGT measurement represents energy that is being generated at a time when the cylinder is under relatively low pressure and temperature, in an unstressed condition. On the other hand, CHT gives us an indication of stress on the cylinder.
EGT simply gives us a measure of inefficiency, the energy the engine was unable to extract from the fuel-air mixture during the power stroke and is therefore simply being dumped out the exhaust and wasted.
More energy goes out the exhaust than is extracted and passed to the crankshaft.

What EGT really means

- **Limiting CHT** is essential to limit stress and ensure cylinder longevity.
- **Limiting EGT** accomplishes nothing useful.
- **Leaning to a particular absolute EGT value** makes no sense at all.
- **NOTE:** In turbocharged aircraft, **limiting TIT** is necessary to protect the turbocharger turbine.

Limiting CHT is essential in order to reduce stress on the cylinder, thus ensuring that it lasts a long, useful life, and doesn't wind up requiring cylinder work on a frequent basis.
On the other hand, limiting EGT accomplishes nothing particularly useful, because high EGT does not mean that the engine is under stress.
In fact, most of the time it means the opposite: most of the things that cause EGT to be elevated, are things that actually cause the engine to produce less power and to be under less stress. For example, if a spark plug does not fire, EGT increases. This happens during every run-up: When a mag is shut off, the EGT jumps up some 7,500 degrees.

The temperature increases even though the engine is under less stress. When only one spark plug fires, the mixture burns much slower and produces less power. That is why the RPM drops when a mag is shut off. The engine is producing less power, but EGT to rises.
Similarly, if the mag timing is retarded, and the spark plug is firing too late, EGT will rise. This does not mean the engine is under greater stress. When we have retarded timing, CHTs go down, EGTs go up, and the engine produces less power than it is supposed to.

Increased EGT means the engine isn't extracting less energy from the fuel, as it is supposed to, and more of it is getting wasted out the exhaust.
Trying to keep EGTs below some value not only doesn't make any sense, but it is counterproductive. Instead, CHT should be monitored because it is the closest measure we have of how much stress the engine is under.

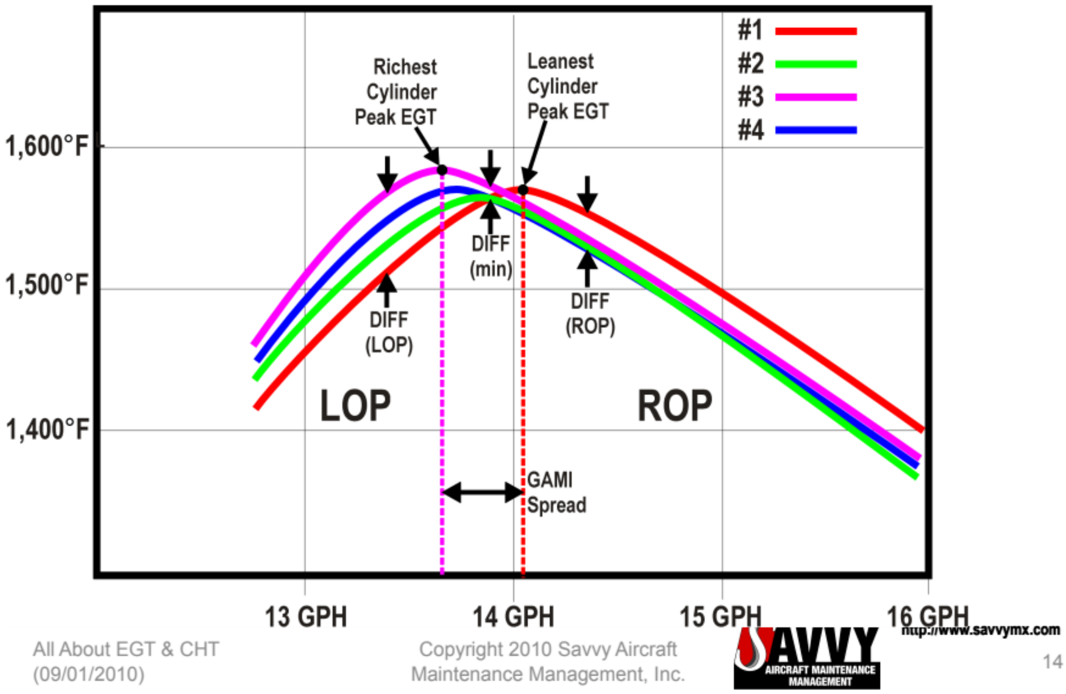
The one exception is in a turbocharged aircraft: often a TIT probe is installed (turbine inlet temperature). It is exactly the same kind of probe as the EGT probe. It is just mounted in a different place, downstream in the exhaust system, as close as possible to the inlet of the turbocharger turbine. A probe in that position no longer sees little brief pulses of exhaust gas punctuated by long periods of nothing.

It is surrounded by a steady flow of gas, and it therefore measures a real gas temperature. Tipically the TIT temperature is kept at 1650 or 1750 ºF in order to protect the turbocharger turbine blades from overheating and getting deformed.

The flattop myth is that in a properly running, well balanced engine, it is desirable to have all of the EGTs the same. The EGT bar graph should have a flat top. Differences between EGTs should be minimized.

Instrument manufacturers tend to reinforce this myth by having the instruments display the differential between the highest and lowest EGT - as if it mattered. On the JPI instruments this is called DIFF and it is one of the numbers that gets displayed on the instrument. What leads to aircraft owners trying to get EGTs closer together, striving for the lowest DIFF. However, this is not important.

The “flat top” myth



Here's a simplified drawing of a four-cylinder engine and its EGT curves.

The difference between EGTs (DIFF) varies depending on the mixture. It tends to be smallest when operating close to the peak EGT region, a region where operation is undesirable.
If the mixture is richened to a reasonable rich of peak (ROP) setting, or especially if it is leaned to a reasonable lean of peak (LOP) setting, the difference gets much larger. The notion that DIFF should be minimized is just wrong, because it implies operation in the peak EGT region, therefore undesirable.

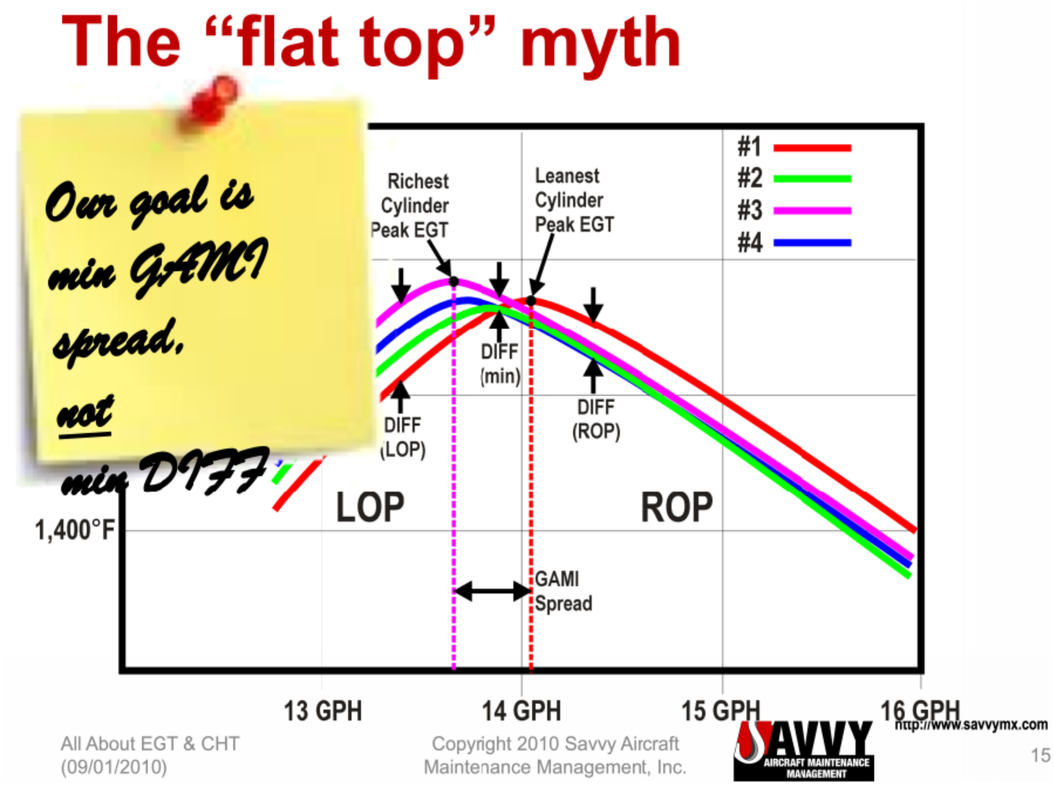
The measurement of importance is the **GAMI spread**: the difference in fuel flow between (a) where the richest cylinder reaches peak EGT, and (b) where the leanest cylinder reaches peak EGT. In a perfectly balanced engine, all of the cylinders should reach peak EGT with exactly the same mixture.

The mixture distribution is always imperfect, so the cylinders never reach peak EGT at exactly the same mixture, but the objective is to get them to reach peak EGT as close to the same mixture as possible.
The smaller we can make the GAMI spread, the more efficient and smoothly the engine will run. In particular, the better it will run in the lean side of peak.

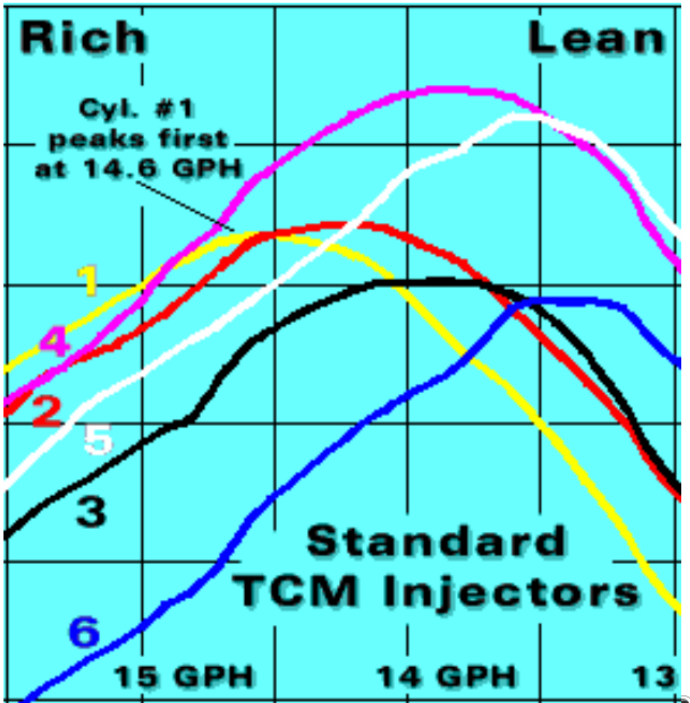
GAMI spread is determined through a GAMI lean test, where measurements are started with a rich mixture and gradually leaned, noting the fuel flow at which each cylinder peaks and the differences between these fuel flow measurements.

The difference in fuel flow between where the richest cylinder peaks and where the leanest cylinder peaks is the GAMI spread.
General rule of thumb for the GAMI spread is less than a gallon an hour, and preferably less than half a gallon an hour for optimum efficiency and optimum lean of peak operation.

The smaller the spread is, the further lean of peak will be able to lean the engine before it starts running unacceptably rough.

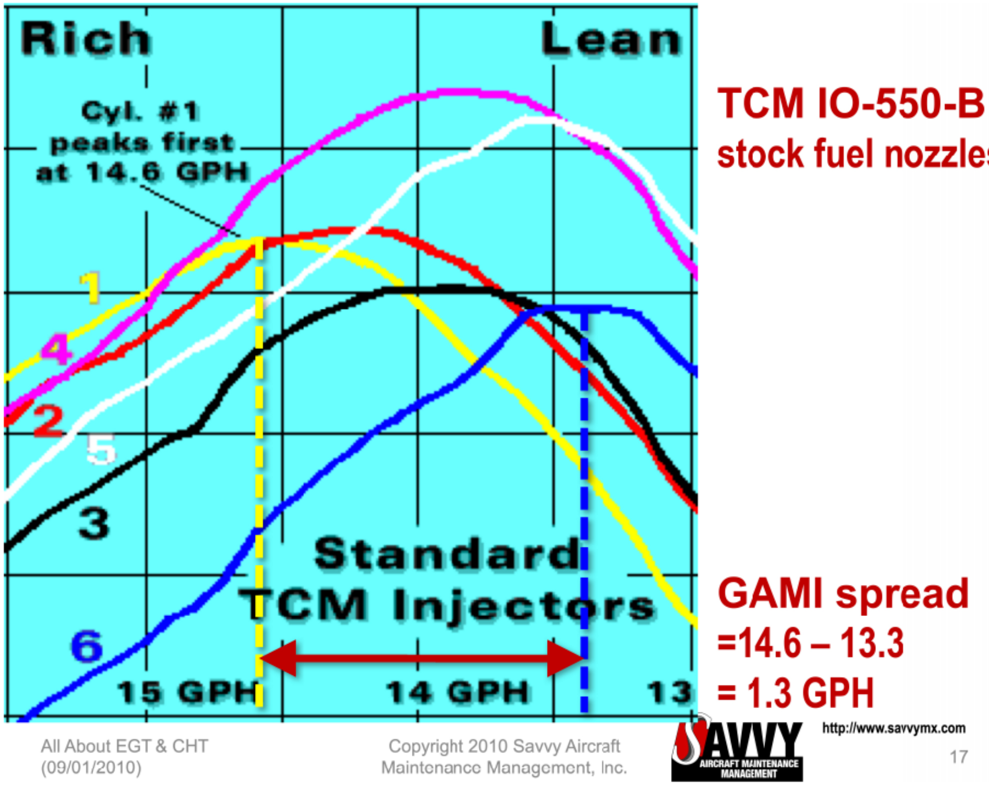


It is important to remember that the goal is minimum GAMI spread, not minimum DIFF.
DIFF can be a useful when, for example, there is a sudden increase in DIFF in cruise flight. In such a stable situation, it is a sign that some cylinder had a big change and there is probably something wrong that needs investigating.



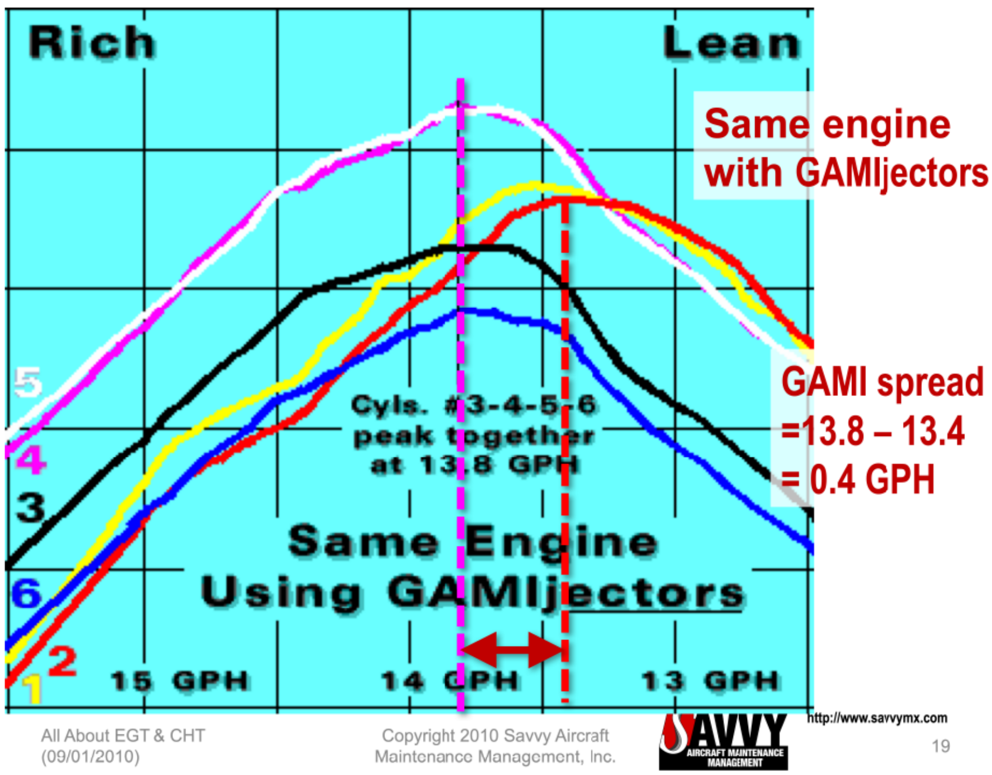
TCM IO-550-B
stock fuel nozzles

Here's some real data from a Bonanza's IO-550. It was equiped with stock, untuned fuel nozzles, as it came out of the TCM factory.



To determine the GAMI spread, the following steps were taken:
The leanest cylinder is #1 (yellow line), as it peaks first.
It peaks at 14.6 g/h (gallons per hour).
As the mixture continues to be leaned, #1 goes lean of peak and the other cylinders keep rising, and reach their respective peaks at various points.
Cylinder #6 (blue line) is the last one to peak, at 13.3 g/h.
Therefore, the GAMI spread is 14.6 - 13.3 = 1.3 g/h

This is considered a very high spread. This engine would not run very well lean of peak. It is going to be significantly less efficient than it should be, and probably burn an extra gallon per hour compared with a properly tuned engine.



When this same engine is equipped with tuned injectors, this is the graph produced.
Not perfect, but considerably better. In fact, now the leaner cylinders are three, four, five and six, all in dead heat, while one and two are running a little bit richer. The GAMI spread is only 0.4 g/h which is quite good.

IT is possible that if these injectors were continued to be tweaked just a little bit we might even be able to bring this spread down a little bit more.
As it is, this engine is now an excellently tuned that will run very efficiently and very well on the lean side of peak. And still, there's a big spread between the hottest EGTs and the coolest EGTs. The DIFF and it is quite large, but it does not matter.
What's important is that within fairly close tolerances, all of these cylinders are running at the same mixture, and they are reaching peak EGT at just about the same fuel flow.

So what good is EGT?

If EGT is not a real number and limiting EGT is not a rational thing to do, then what good is EGT?
Here's an example of an engine that has these EGTs and you can see they're definitely not at all a flat top, but this engine happens to be almost perfectly balanced and is running very, very well.

So what good is EGT?

EGT is sensational for troubleshooting.
CHT will help in operating the engine and keeping it out of the danger zone. But when something goes wrong with an engine, EGT is absolutely invaluable for figuring out what is wrong.

EGT troubleshooting tips

Malfunctioning magneto will cause <u>elevated EGT on all cylinders</u>, with normal or slightly depressed CHTs

- **Consider confirming with an in-flight mag check** but be careful because the engine might quit when you switch to the failed mag. If it does, throttle back to idle before you turn the mag back on to avoid an afterfire and possible exhaust system damage.

If a magneto is malfunctioning, it will cause EGT on all cylinders to rise. CHTs will remain or go down slightly, but all EGTs will all rise sharply. Typically, around 7500 ºF.
When something goes wrong with the magneto, it affects all cylinders, not just one.
When something like this happens, confirming it with an in-flight magnet check should be consider.
If the magnet has failed completely, and engine operation is switched to that magnet, clearly the engine is going to quit. Nothing serious, but immediately switching back to both magnetos, would likely cause a big bang or a big after-fire in the in the exhaust system, because while the engine wasn't producing power, fuel was still being pumped into the engine.
So if the engine quits, the throttle should be brought back to idle, then the mag turned back on, then gradually throttle advanced.
This should avoid the possibility of an after-fire.

EGT troubleshooting tips

Defective or fouled spark plug will cause <u>elevated EGT on one cylinder only</u>, with normal or slightly depressed CHT on the affected cylinder

- **Confirm by doing an in-flight mag check** and noting which mag causes the affected cylinder to go cold

If only one cylinder has an elevated EGT, then that is clearly not caused by a mag, because there's nothing a mag can do that will affect only one cylinder. It is almost certainly a problem with a spark plug not firing. It could conceivably be an ignition lead but 98% of the time it is a spark plug.

If the engine is turbocharged and has a TIT (turbine inlet temperature) readout, it will probably rise when one EGT rises. In this particular case, the EGT is up on only one cylinder: cylinder number five on the left engine and all the other EGTs have remained the same. This indicates that a spark plug is not firing.

It is a good idea to confirm by doing an in-flight magnet check. When only the magnet powering the bad spark plug is active, the engine will run rough and the corresponding EGT bar will start to fall to zero. When both mags are again active, the display will return to the previous state.
Summarizing: elevated EGT on one cylinder is typically a spark plug that stopped firing, and elevated EGT on all cylinders is typically a mag that stopped working.

EGT troubleshooting tips

Partially clogged fuel injector nozzle will cause:

- elevated EGT and CHT on one cylinder only if you're ROP
- reduced EGT and CHT on one cylinder only if you're LOP (plus probable engine roughness).
  - **Go full rich, land, and dump your engine monitor data.**

A partially clogged fuel injector will normally cause both EGT and CHT to either go up or to go down, but they both go in the same direction. If rich of peak, a partially clogged fuel injector will cause EGT and CHT to rise. If lean of peak, it will cause EGT and CHT to fall, and obviously if the injector is clogged enough, it might even cause that cylinder to flame out. So the EGT and CHT fall profoundly and the engine will run rough.

If the injector is clogged, go full rich and then land and dump your engine monitor data to determine what happened.

EGT troubleshooting tips

Completely clogged fuel injector nozzle will cause the engine to run rough, one EGT to go cold, and the associated CHT to drop.

- **Attempt to unclog by going to full-rich mixture and momentary high boost pump.** If engine continues to run rough, land as soon as practicable.

If a fuel injector completely clogs, then obviously it will shut down the cylinder completely and will cause one EGT to go completely cold, the associated CHT to drop profoundly. It may be possible to unclog the injector by going to full rich mixture and momentarily activating that the high boost pump. But if the engine continues to run rough, then just land as soon as practical. The engine will be shaking, because it will be running on n-1 cylinders.

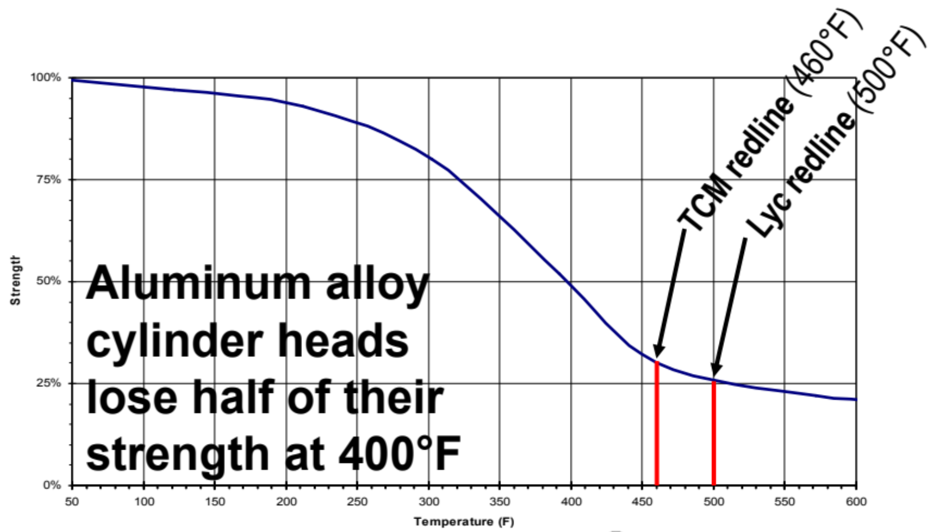
Limiting CHT and EGT

- **Limiting CHT is key to engine longevity**
  - CHT is best proxy we have for peak pressure
  - High peak pressure means high engine stress
  - High CHT increases probability of head cracks
- **Limiting EGT is not helpful or logical**
  - EGT is not a measure of engine stress
  - EGT often increases when stress decreases
  - EGT is primarily useful for troubleshooting

Bottom line, it is very important to limit CHT. That is the key to getting long life out of the cylinders, because CHT is the best proxy for peak pressure, so peak pressure is kept under control by keeping CHTs under control.

Limiting EGT is not particularly helpful or logical, since it is not a measure of engine stress, and it often increases when stress decreases.
EGT is primary use is for troubleshooting.

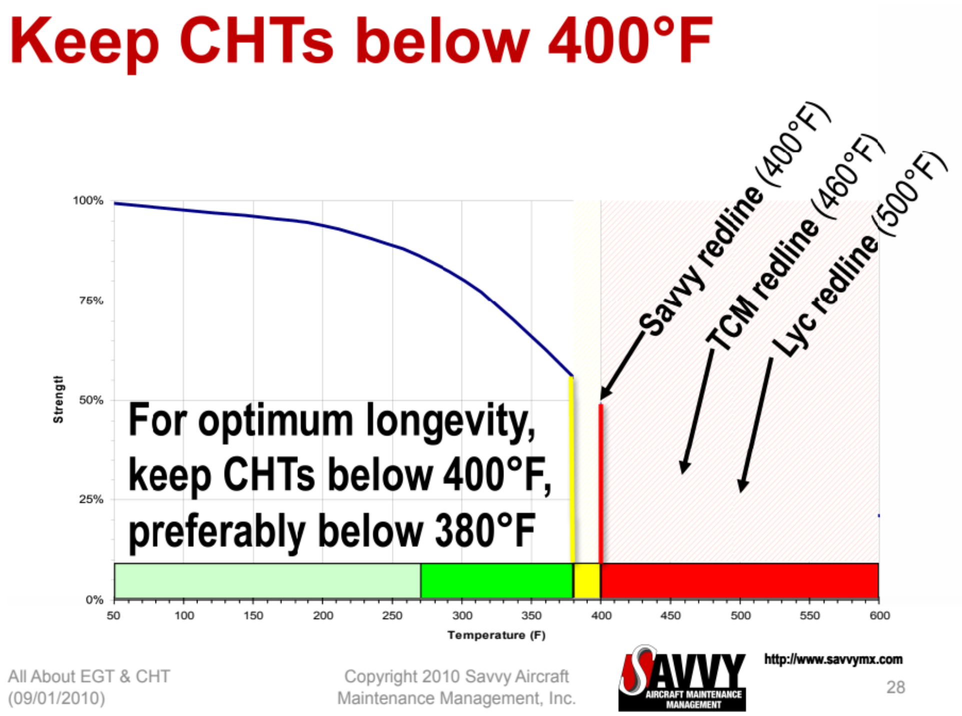
CHT vs. cylinder head strength



Cylinder heads are made of aluminium alloy, and their strength drops fairly significantly as temperature rises. When temperature rises to 400 ºF, the cylinder head has lost about half of its tensile strength.

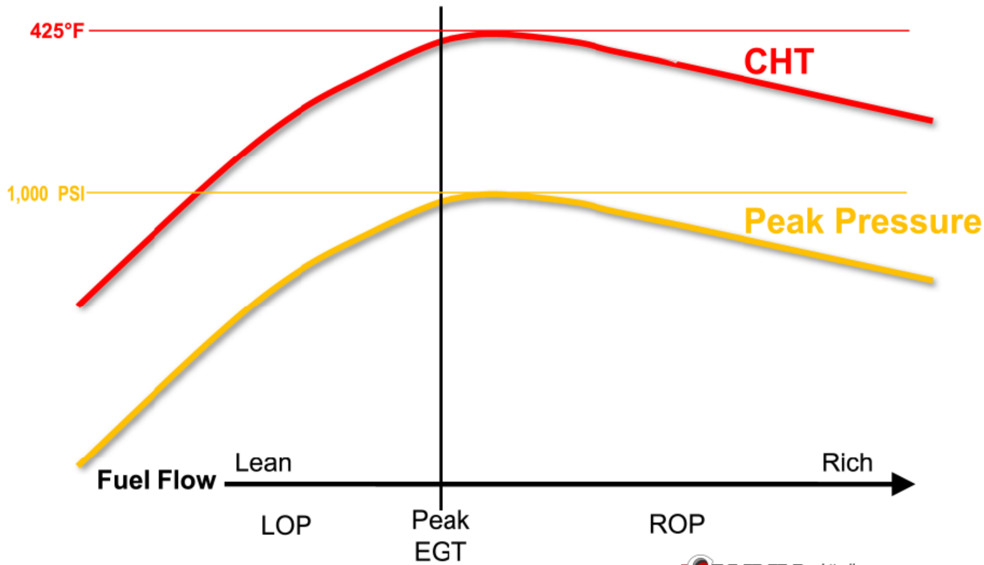
As temperature increases above 400 ºF, the tensile strength continues to drop quite rapidly. TCM sets a CHT redline at 460 ºF. Lycoming normally sets it at 500 ºF. **I'd like to try to convince you that both of those temperatures are absurdly high, and we never ever want to let CHT get anywhere remotely close to these manufacturers read line numbers!**

Those numbers should be considered absolute emergency numbers. Cylinder head temperatures should be kept below 400 ºF and preferably lower than that.

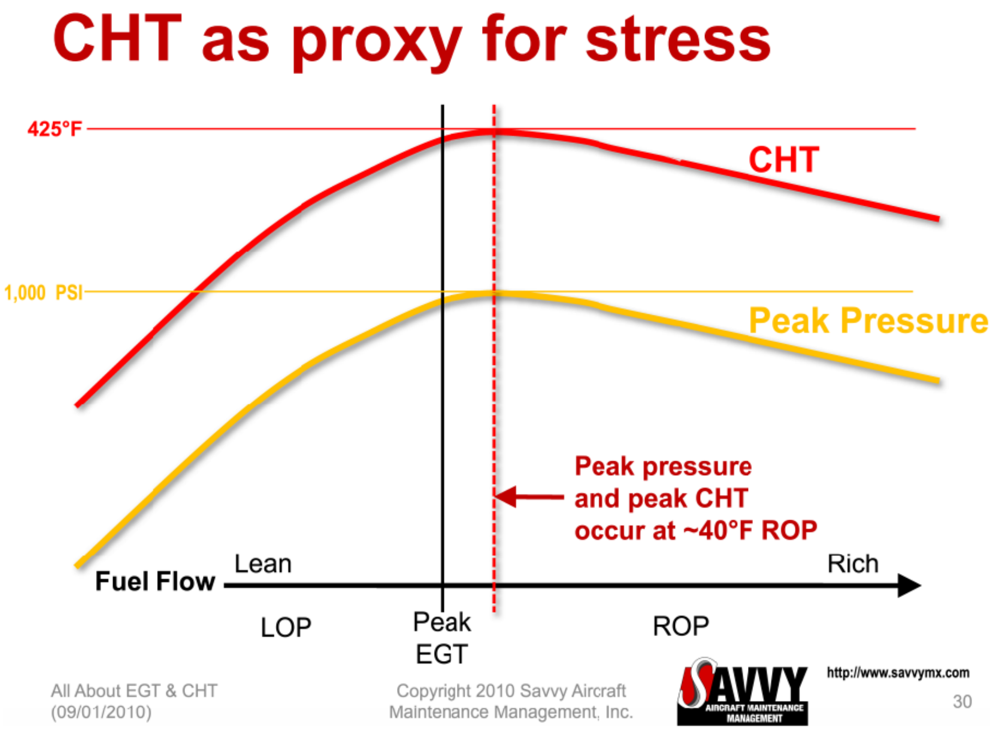


Red line should be at 400 ºF and yellow line between 380 and 400. Ideally, cylinder head temperatures should stay at 380 ºF or less. If CHT starts getting above 380 ºF, something should be done to bring it down, and if CHT gets up to 400 ºF something fairly aggressive should be done to bring it down. It should not get above 400 ºF.

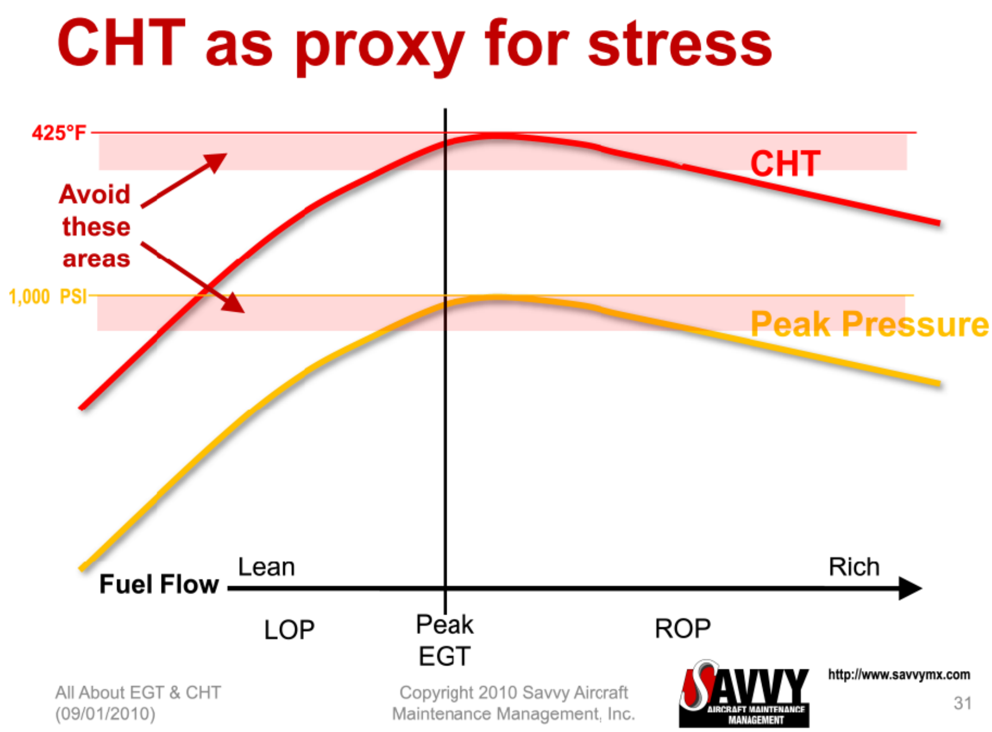
CHT as proxy for stress



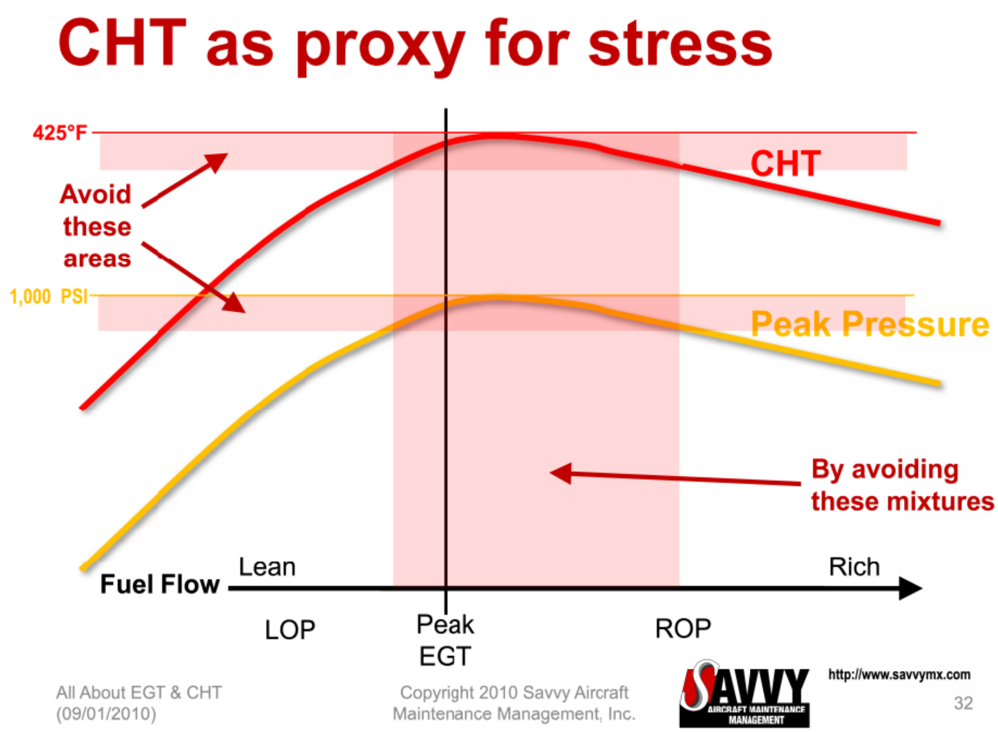
This graph shows that the shape of the peak pressure curve and the shape of the CHT curve as a function of fuel flow, are roughly the same and they peak at about the same spot.



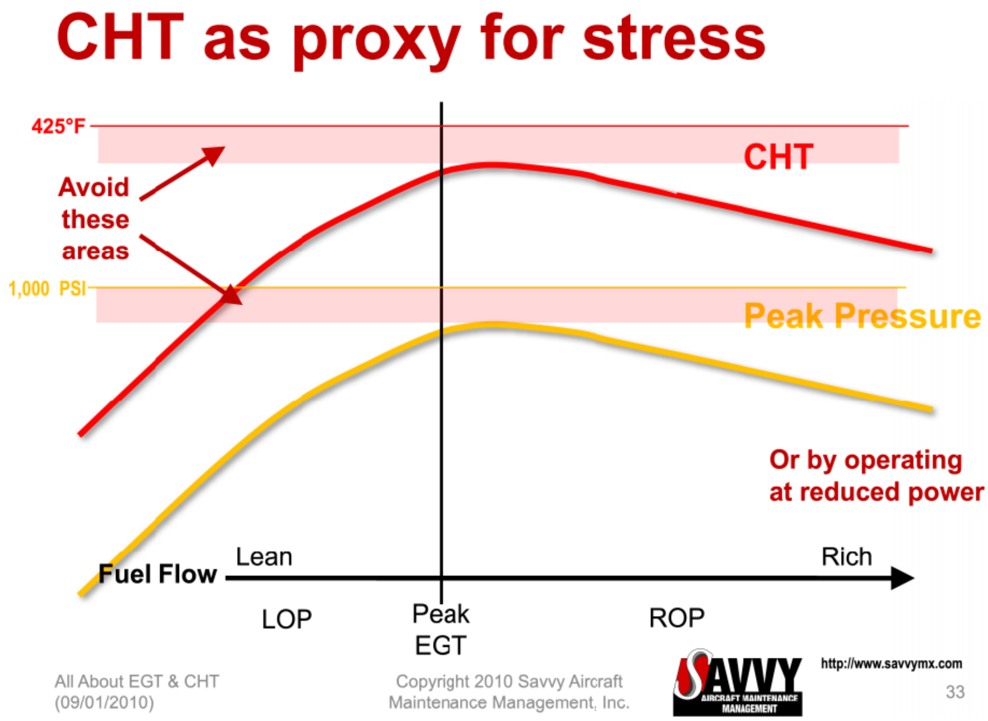
Both of these curves peak at a mixture of approximatelly 40 degrees rich of peak. That is the mixture at which the power assemblies are being stressed the most. Unless when running at quite low power, this area should be avoided, by either staying on the rich side or on the lean side.



It is possible to exit the red zone in this graph by enriching ot leaning the mixture.
Note that, due to the different slopes, it only takes a little leaning, but considerable enriching to get out of the red zone, bringing down CHTs and peak pressure.

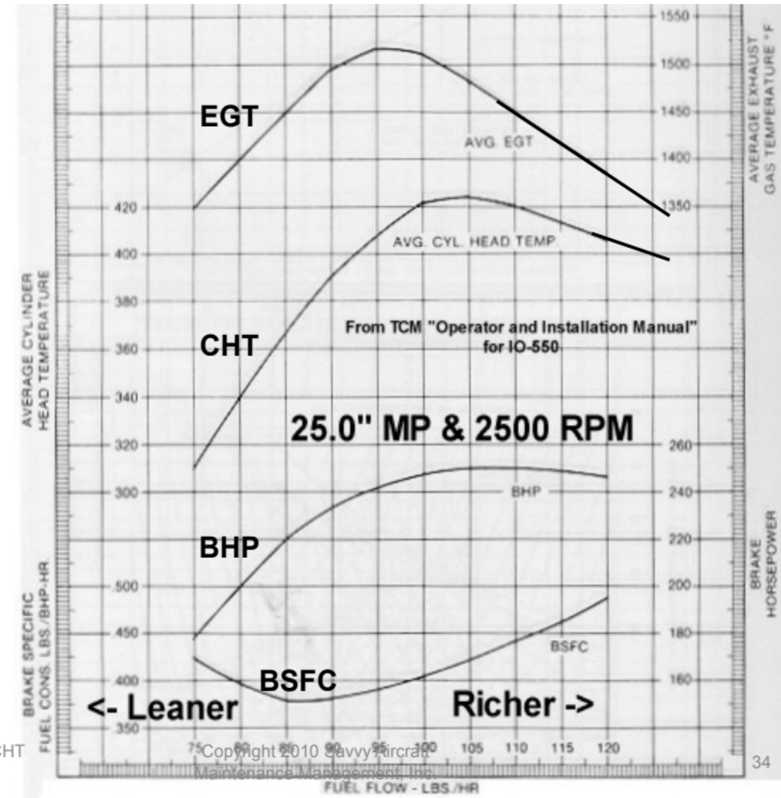


It is possible to stay out of the high stress areas by avoiding these mixtures. This area is typically referred to as "the red box".
To stay out of that area, the engine should be leaned, and if it is sufficiently lean of peak or sufficiently rich of peak, the danger zone can be avoided.

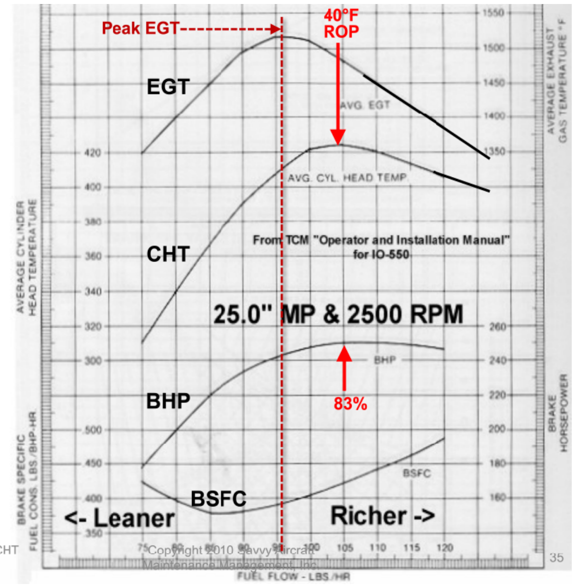


Reducing power is an alternative. In this case, both of these curves shift down, and if the power is reduced enough, then the mixture control can be placed anywhere whithout producing harmful temperatures and harmful pressures.

In short, power can be reduced and speed sacrificed, or proper mixture management exercised, either by operating lean of peak or by quite rich of peak.



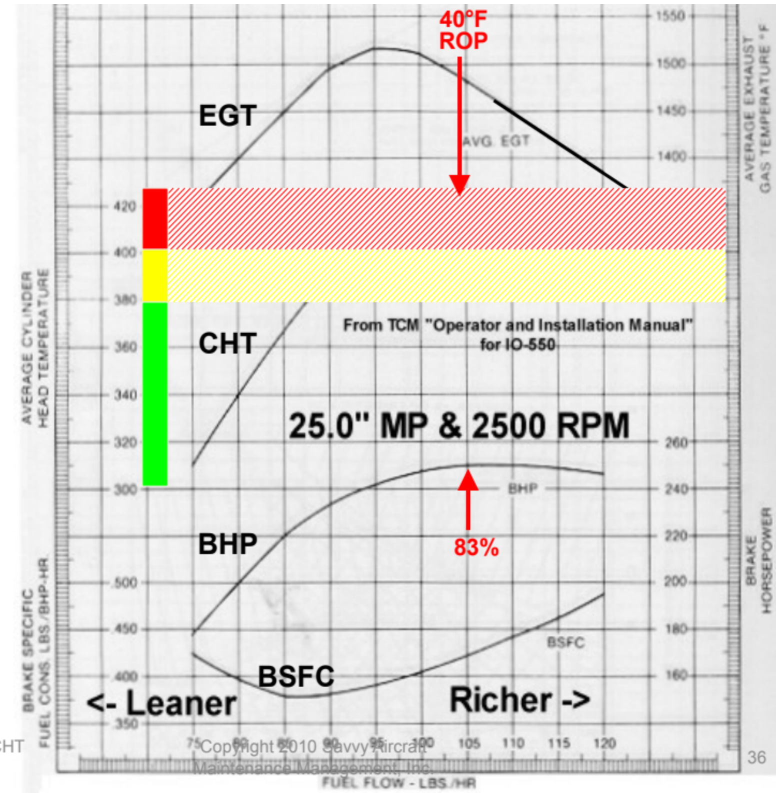
This is a diagram from the TCM operator's manual for the IO-550 engine. There's nothing special about IO-550s. The curves for any engine will look essentially the same as this, at least the shapes and relationships will be the same.



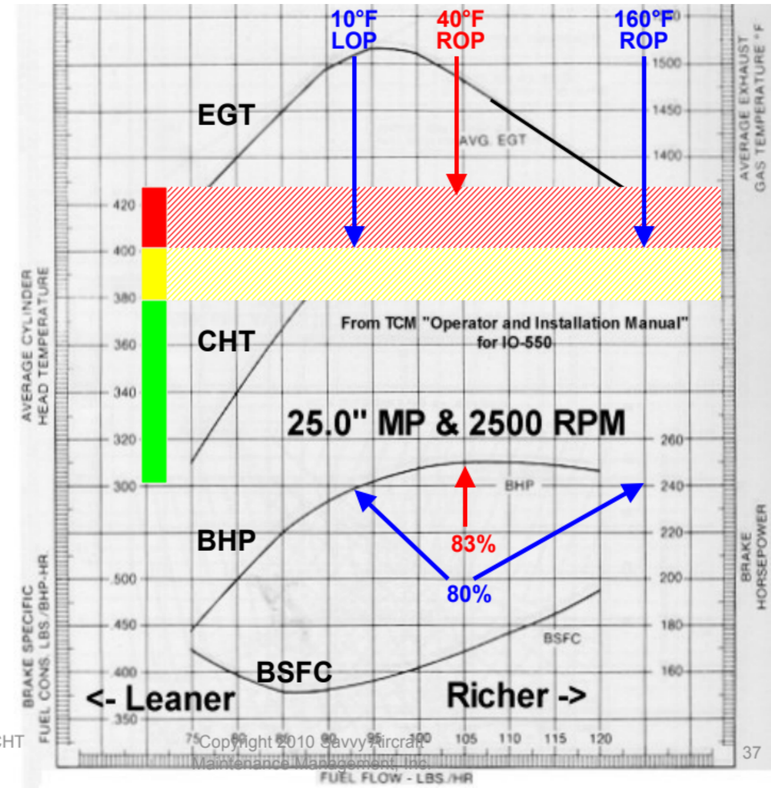
This chart was for 25 inches of manifold pressure in 2500 rpm on this normally aspirated IO-550 engine.

The vertical dotted line is peak EGT. Note that the peak CHT and the peak cylinder pressure occur at about 40 degrees rich of peak, and operating at that point, which is the worst possible mixture to operate at in terms of engine stress, this engine would be putting out 83% power.

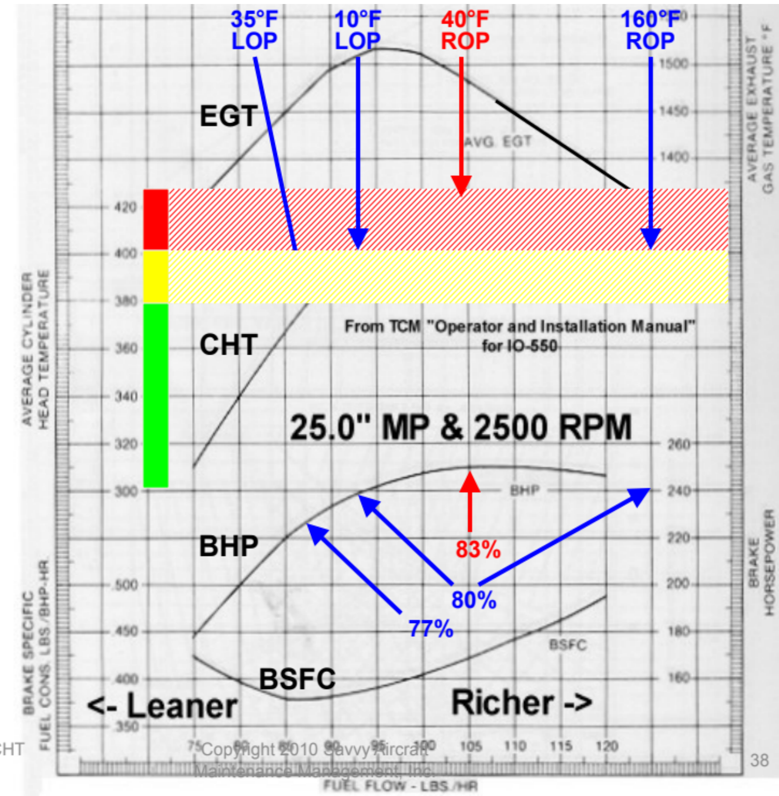
However, the cylinder head temperature would be about 425 degrees ºF, which is not an acceptable temperature. It is certainly below the redline of 460 ºF, but at this temperature the cylinders will be damaged.



Superimposing the EGT scale shows that there are two ways to reduce CHT below 400 ºF: to lean or to enrich the mixture.



It will take about 10 degrees lean of peak to bring the temperature down to 400 ºF. Or alternatively, it will take 160 degrees rich of peak to do the same thing. Either way, the horsepower will drop from 83% power to 80% power. The effect on air speed, the square root of horsepower, would be approximately a 2% reduction. In a 160 knots airplane, about 3 knots would be lost, and that would be the trade-off for getting much better cylinder longevity. Of course, a more conservative 380 ºF would be better for the cylinders longevity than 400 ºF.



The mixture should be changed to 35 lean of peak to bring CHT down to 380 ºF or richen by an amount that is off the scale. The horsepower now drops further to 77% and, assuming a 160 knot airplane, another three knots would be lost.

That is the necessary trade-off: to treat these cylinders right, a bit of airspeed must be sacrificed.

CHT is an imperfect proxy

In addition to stress (i.e., peak pressure)**,**
CHT also is affected by:

- **OAT** (deviation from ISA temp)
- **Airspeed** (less cooling at low airspeed)
- **Altitude** (less cooling at high altitude)
- **Cooling system efficiency** (design, condition)

CHT is an imperfect proxy because although the shape of the curve is the same as the shape of the peak pressure curve, it also is affected by other factors:

Outside air temperature: In hot day, CHTs are going to be higher than they would otherwise be. "Hot day" meaning above a standard atmosphere. For instance, at 17,000 feet, outside air temperature at freezing is a "hot day", because standard temperature at 17,000 feet is -18.7 ºC. In this case, CHT is going to be higher. In a very cold day, CHT is going to be lower, so the red line should be adjusted accordingly.

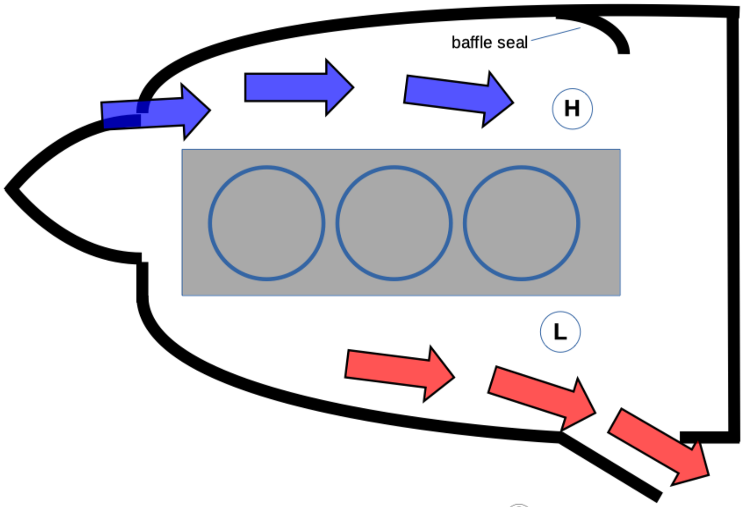
Air speed: In a steep climb, with low air speed, not much cooling air will pass over the cylinders. So, CHT is higher.

Altitude: at high altitudes, the air is thinner. This is a situation similar to air speed: at high altitudes indicated air speed will be lower for the same true speed, and the cooling is mainly a function of indicated airspeed.

Cooling system efficiency: (a) design efficiency - for example the cooling system in a Cessna 310 or in a Bonanza is much less efficient than the cooling system in a Cirrus SR22 or Diamond DA40. All other things being equal, the Cirrus is probably going to run twenty degrees cooler CHTs than the 310, just because it is a more efficient cooling system by design.

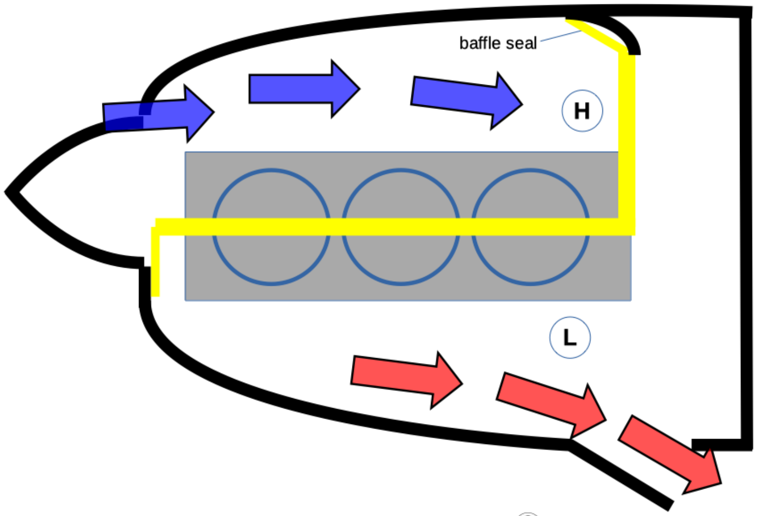
(b) the condition of the cooling system makes a big difference. If baffles are out of place, or baffle seals are not in good shape, CHTs will be higher simply because the cooling system is not in a state of good repair.

The engine cooling system



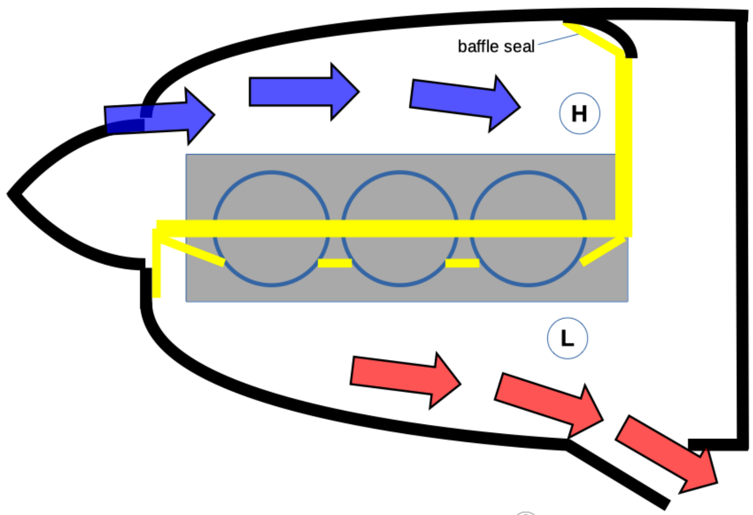
Cooling system - most airplanes are cooled this way.
Ram air enters the cowling on the top side of the engine, creating a high pressure area. A fixed or adjustable opening in the cowlingcreates a low-pressure area under the engine. The air flows from the high pressure on top of the engine, through the cooling fins on the cylinders, into the low-pressure area in the bottom of the engine, and thus carries heat away.

The engine cooling system



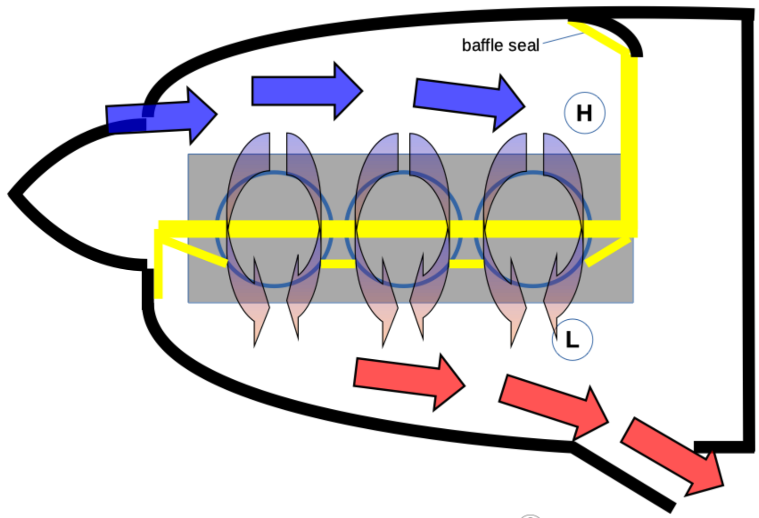
Metal baffles and flexible rubber, like baffle seals, together create a barrier between the upper high-pressure compartment and the low-pressure compartment, so that when the air flows from the high to the low pressure areas, it is forced through the cylinder cooling fins.

The engine cooling system



In addition to the baffles, a series of inner cylinder baffles, small plates that installed below and between adjacent pair of cylinders, force the air through the cooling fins.

The engine cooling system



The baffles and baffle seals create the parth for the air, from the upper to the lower area, passing through the cylinder fins. Anything wrong with the baffles or the baffle seals, will cause cooling losses and CHTs will run higher than they should.

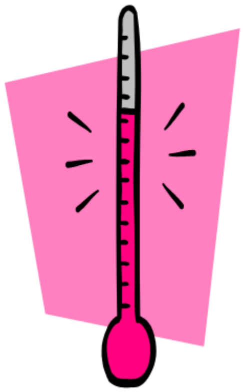
Do you know your CHTs?

Not unless you have a multi-probe engine analyzer!

- CHT spread is often 50°F to 100°F
- Hottest cylinder is often <u>not</u> the one with the factory CHT probe

Every piston airplane needs to have a multi-probe engine analyzer, with a CHT probe on each cylinder, given how critical these measurements are. The standard factory instrumentation that until recently used to come with most GA airplanes only measured the CHT on one cylinder. There was no guarantee that that CHT was the hottest one. So chances were one out of four or one out of six of catching a cylinder problem, only one cylinder was monitored.
There seems to be a misconception that multi-probe engine analyzers are only necessary in high performance airplanes. The fact is that they are even more important in low-performance airplanes.
The less cylinders the engine has, and the less power it produces, the more critical it is that all of those cylinders are working properly.
Consequently low performance airplanes - Cessna 182s, Cessna 172s, Piper Cubs, etc. - need this type of instrumentation, even more than high-performance airplanes do.

Reducing CHT



- **Open cowl flaps** (if you have them)
- **Increase airspeed**
- **Adjust mixture**
  - Hottest CHT occurs ≈ 40°F ROP
  - If ROP, richen a lot
  - If LOP, lean a little
- **Reduce power** (if all else fails)

The lower performance the airplane, the more critical it is to have good engine instrumentation.
To bring CHT down, several actions can be taken:

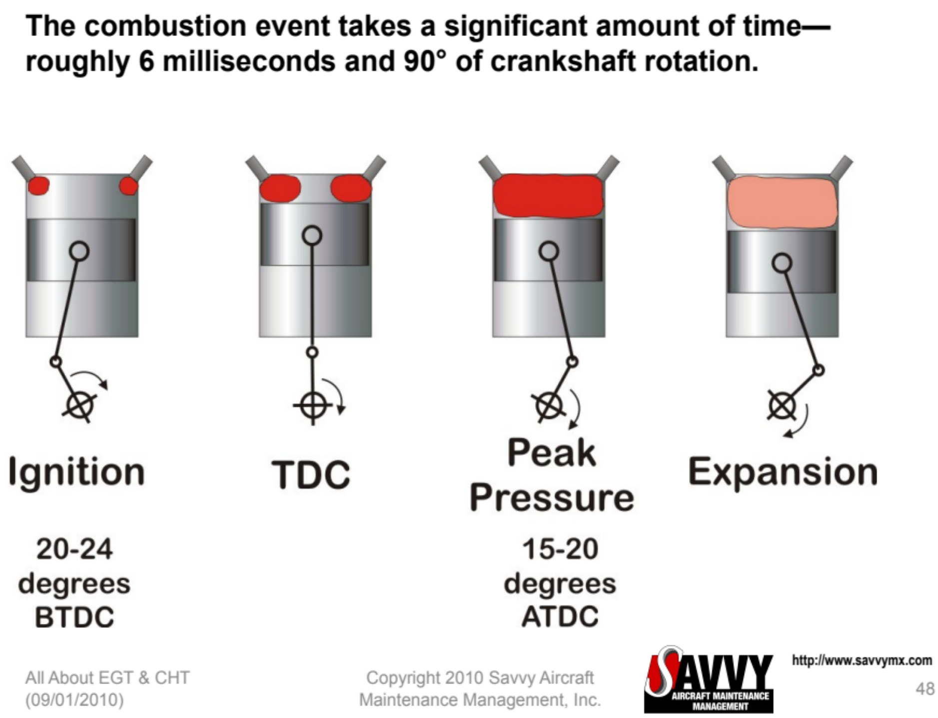
- Open the cowl flaps if so equipped.
- If in a climb, put the nose down, and increase airspeed more cooling air reaches the engine.
- Adjust the mixture away from the area around 40 rich of peak:
- if running rich of peak, richen substantially;
- if lean of peak, probably leaning a little will bring the temperatures down, because the curve is so steep on the lean side of peak
- And if all else fails, throttle back.

But we just don't want to sit there watching cylinder head temperatures climb without doing something about them.

Abnormal combustion events

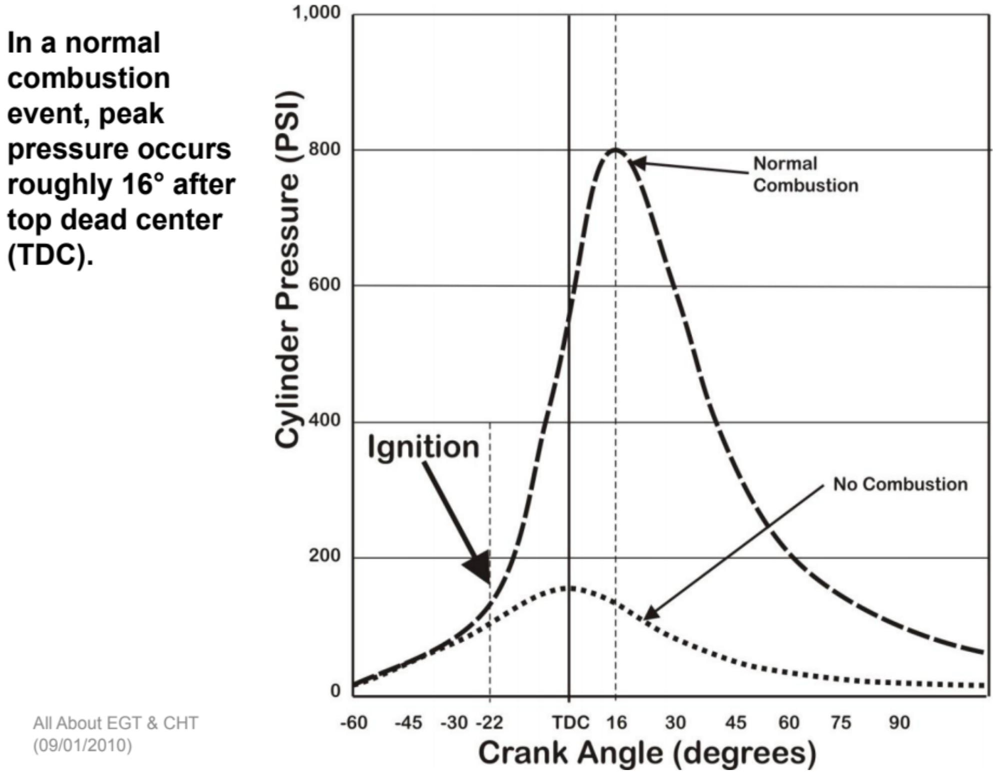
- **Detonation**
- **Pre-ignition**

Rising cylinder-head temperatures can be indicative of an abnormal combustion event that could actually damage the engine unless arrested.
The two abnormal combustion events we normally focus on are called detonation and pre-ignition.



They're often confused with one another. They're quite different and one is more harmful than the other .

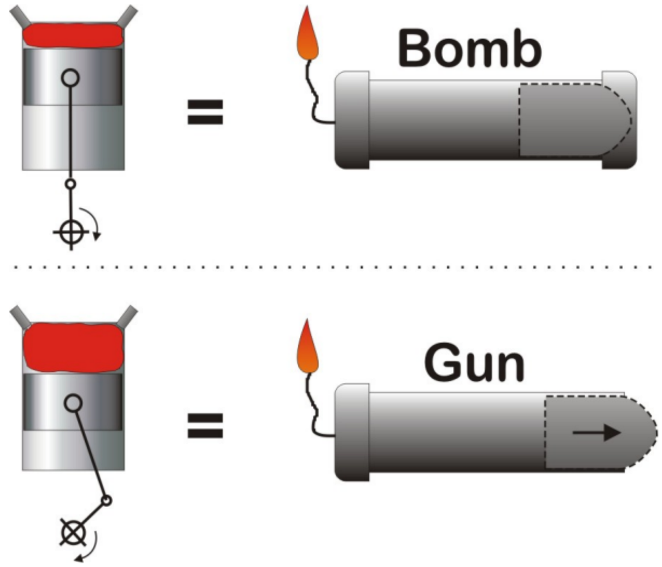
A combustion event is not an explosion, it is a smooth burning event that normally takes a fair amount of time - roughly six milliseconds or so. Each time it happens, it starts at typically twenty to twenty-four degrees before top dead centre, when the spark plugs fire, and then it continues as the piston gets to the top of its travel, and starts back down into the power stroke.
Normally the combustion event is fully developed and reaches its peak pressure at somewhere between fifteen and twenty degrees after top dead center, and then gradually starts to cool down as the piston goes down and the gas expands and cools.



The pressure inside a cylinder is lowest as the piston starts going up in the compression stroke. The pressure starts to increase. When the spark plug fires, the combustion event starts and the pressure starts rising very rapidly. It continues to rise past top dead center, to the peak point - in this case around 16 degrees after top dead center - and then it starts coming back down.

The peak pressure point in this case is 800 psi, occurring at 16 degrees after top dead center which is about the optimum point.

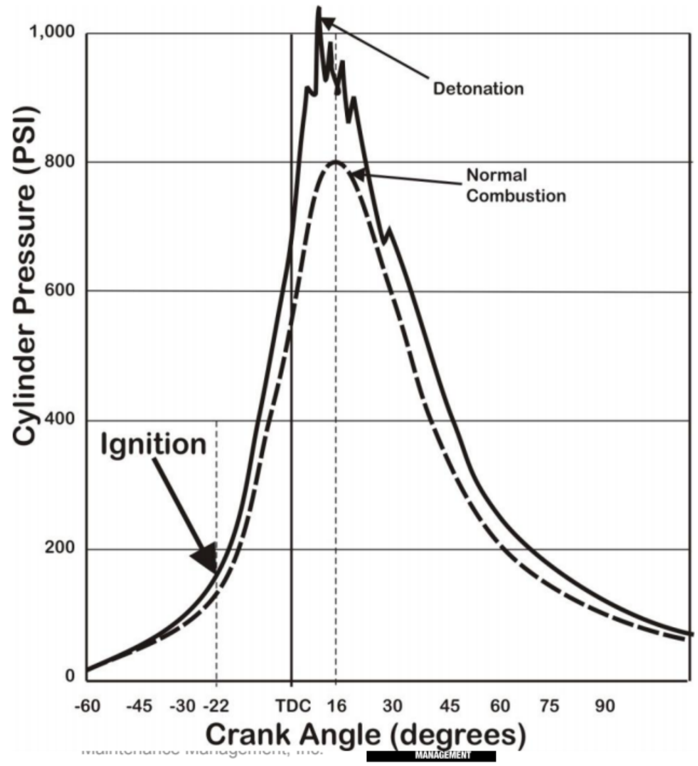
It's crucial that peak pressure occur well past TDC, because the geometry of the crankshaft and connecting rod near TDC does not permit combustion pressure to be converted into useful work (i.e., crankshaft rotation.



It is very important that the peak pressure point occurs well after top dead center, when the crankshaft and connecting rod are in a position where the pressure can be converted into useful work, i.e., rotating the crankshaft. If peak pressure occurred, for example, right at top dead center, then there would be nowhere for the piston to go: it would essentially lock in position and all that pressure would be spent trying to over pressure and over temp the cylinder rather than to push the piston down and do useful work.
This is why timing is so critical.

If the combustion process moves too fast, the peak pressure occurs too early.

The result can be excessive pressure and temperature, and unstable pressure pulses known as "detonation."



All About EGT & CHT
(09/01/2010)

If the combustion event either starts too early because the ignition timing is incorrect, or if it progresses too rapidly because the mixture is set wrong, then it will reach the peak too early, and it will be very high.

When the pressures and temperatures get high enough, the combustion event - which is supposed to be a smooth burning process - will become unstable. There will be little pockets of abnormally rapid combustion that will set shockwaves inside the cylinder. The pressure will get very high. There will be localized areas of very high temperatures.

The graph above shows a cylinder that is undergoing detonation.

Note the peak, higher than normal combustion, and the several neighbouring peak, which demonstrate that the mixture has stopped burning smoothly and is starting to go off in little abnormal pockets. Like firecrackers, in a sense.

Detonation

- **Not necessarily harmful.** Most aircraft engines can tolerate moderate detonation without damage (although it's not optimal)
- **Heavy detonation can cause** fractured spark plugs, damage to piston rings and lands, pitting of piston crown, piston heat distress (melting)
- **If you keep CHT below 400°F**, destructive detonation is essentially impossible

Detonation is not one of these binary things: It is not a question of either being in detonation or not. Detonation comes in all flavors, from mild to heavy. Mild detonation, or even moderate detonation, is normally not enough to damage the engine, although it is certainly not optimal to have instability in the combustion event, but an engine can get into mild detonation without being harmed.
If the detonation gets heavy enough, it can result in physical damage. It can contract the spark plug insulation, which can have negative consequences: cause pre-ignition, damage piston rings, pit the crown of the piston, and in extreme conditions it can melt parts.

Heavy detonation must be avoided. If CHTs are kept below 400 ºF, it is almost impossible for heavy, destructive detonation, to occur. By keeping close attention to CHTs and making sure they never get too high, the detonation risk will essentially be eliminated.
If CHT rise above 400 ºF, especially if it rises rapidly, quite aggressive action must be taken to ensure that it doesn't continue to rise, as damage can occur.

Heavy detonation damaged this piston and its #1 compression ring.

All About EGT & CHT (09/01/2010)

http://www.savvymx.com

Here's an example of a piston that was damaged by heavy detonation. Pitting on the piston crown is clearly visible. The corner melted to the point where the top compression ring was compromised. Obviously this caused significant damage, and probably got quite a lot of metal in the engine. Undoubtedly a teardown situation.

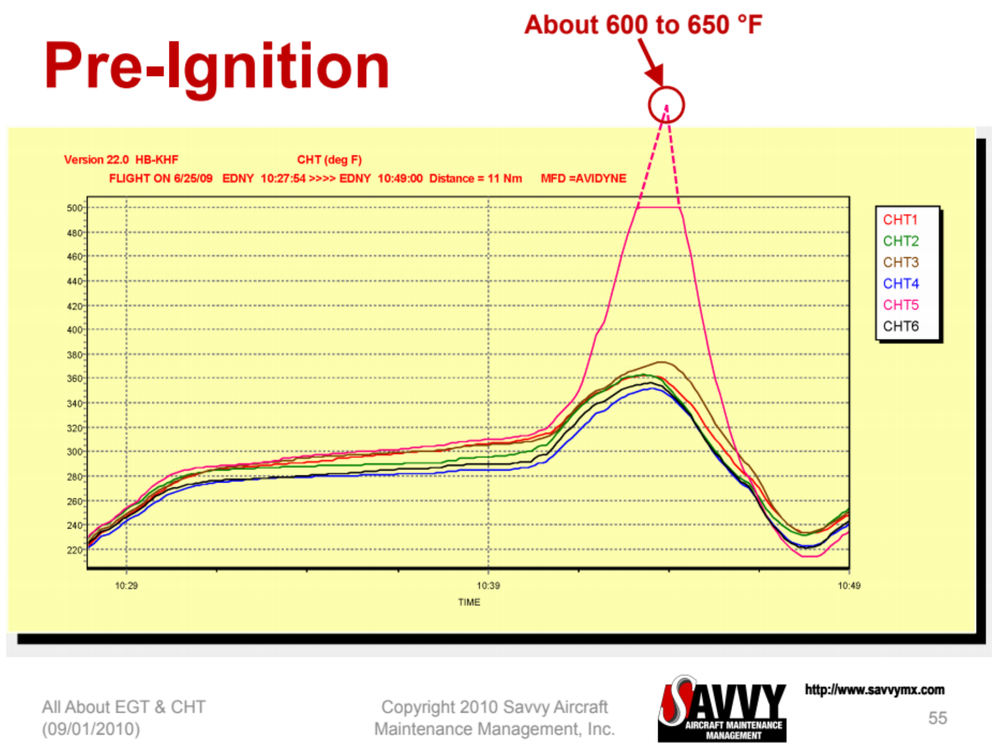
Pre-Ignition

- **Ignition of the air-fuel charge prior to the firing of the spark plug.** Ignition source can be an overheated spark plug tip, carbon or lead deposits in the combustion chamber, or (rarely) a badly burned exhaust valve.
- **Charge ignites early in the compression stroke**, causing tremendous heat and mechanical stress.
- **Substantial damage is almost inevitable.** No engine can survive pre-ignition for very long.

Pre-ignition is a quite different phenomenon. It occurs when combustion starts at a time other than the regular ignition.
It is caused by anything in the combustion chamber glowing red-hot, acting as a glow plug, and igniting the fuel/air mixture without the spark plug triggering it.

For example, if the spark plug insulator fractures, it can act as a glow plug, and can cause pre-ignition.

Pre-ignition is much more serious and much more damaging than detonation. It causes enormous heat and stress on the engine, because effectively, the peak pressure is occurring before the piston reaches top dead center, and it pushes the crank shaft in the direction opposite to rotation. No power assembly can survive pre-ignition for more than in just a few seconds. It puts enormous enormous stress on the components and so it must be avoided at all costs.



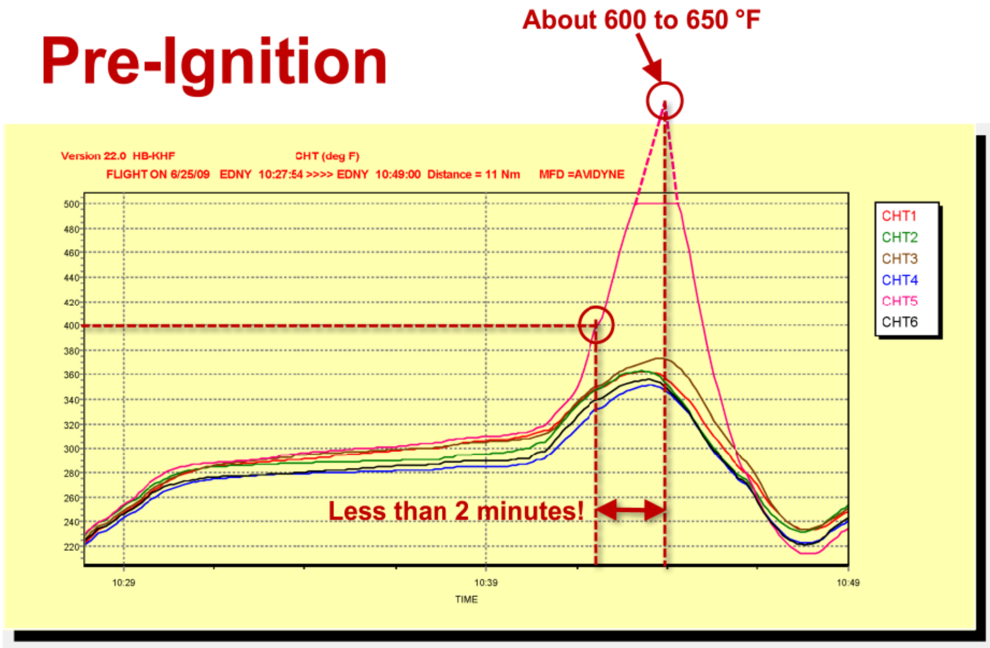
Here's an example of a pre-ignition event that happened in a Cirrus SR20. It was a very new airplane, the engine was hardly out of break-in.

The graph shows CHTs over time.

As the pilot applied take-off power, all CHTs came up in a normal fashion, up to a peak of about 360 to 370 ºF, with the exception of cylinder number one. Number one's CHT started rising in an uncontrolled fashion. When it got up to 500 ºF, the engine monitor, which in this particular case was an Avidyne system, pegged out. The Avidyne system does not record cylinder temperatures above 500 degrees.

The temperature continued to rise to a peak likely around 600 ºF or 650 ºF, at which point the power assembly was destroyed, and everything started plummeting down, and at this point that cylinder went almost cold.

Pre-Ignition

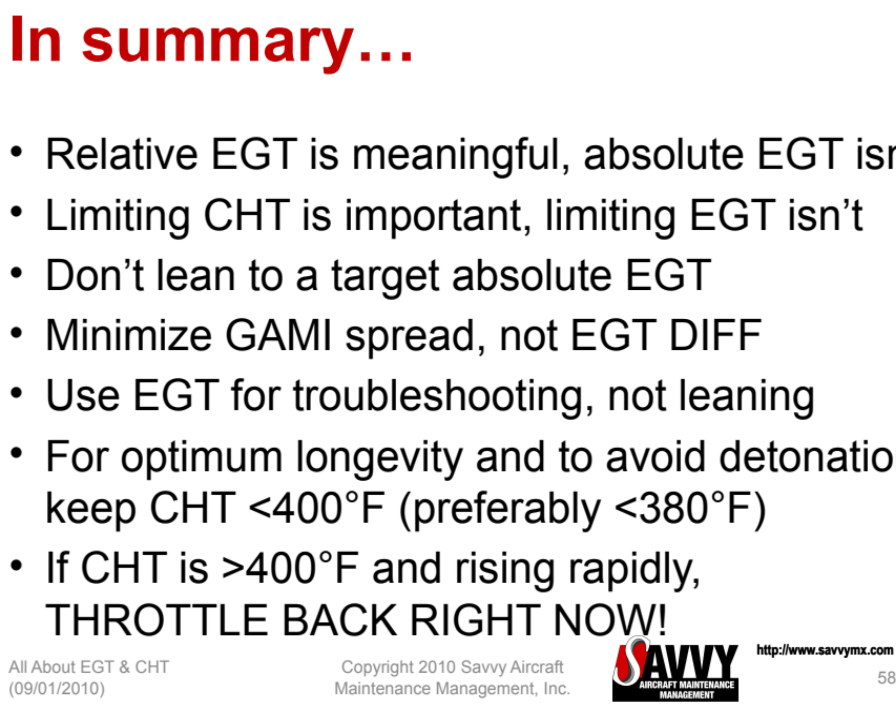


About a minute and a half after takeoff power, the CHT on number one passed 400 ºF. If an alarm was raised, no action was taken. From the time the CHT passed 400 ºF to the time the cylinder was destroyed, less than two minutes elapsed.

This whole destruction occurred about three and a half minutes after he applied takeoff power and in less than two minutes after CHT on number one passed 400 ºF.

And here's what happened: It melted a hole in the piston, the piston crown was clearly above its melting point and there is molten metal everywhere.
The pilot/owner submitted a claim to TCM, as the engine only had about 75 hours since new. TCM turned it down because they never give warranty consideration for detonation of pre-ignition damage.

This airplane is extremely well instrumented, and the pilot had the means to recognize the rapidly rising CHT, going through 400 degrees, as an emergency condition. Had he pulled the power way back and landed, the engine would have not sustained this damage. But despite the fact that he had very good instrumentation, he really didn't know what to do with it and so the engine suffered a catastrophic failure.



- Relative EGT is meaningful but absolute EGT is not meaningful.
- Limiting CHT is important. Limiting EGT is not important.
- Leaning to specific EGT targets is not a good idea.
  In a normally aspirated airplane, as you climb, lean to maintain a constant EGT.
  That is not leaning to a target absolute EGT. That is leaning to a target relative EGT, so a legitimate thing to do.
  In other words, whatever the EGT was out of a thousand feet, should be maintained during the climb to 10,000 feet.
  But this EGT could easily be, 1350 ºF one day and 1425 ºF another day.
- To get a well balanced engine, GAMI spread should be minimized, instead of leaning to a particular number.
  Minimizing the difference between EGTs is not a particularly useful thing. Some of the best balanced engines have fairly wide differences between the hottest and the coldest EGT. That is not a significant number. GAMI spread is important.
- EGTs primary value is in troubleshooting.
- To protect the engine against over-stress and damage, CHT should be monitored.
  For longevity, CHTs should be kept below 400 ºF, and preferably lower than 380 ºF.
  If CHT rises above 400 ºF, and is rising rapidly, engine destruction could happen within one minute.

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https://www.youtube.com/watch?v=fqe9j74qMdk
https://gami.com/gamijectors/leantest.php
https://www.advancedpilot.com/downloads/GAMI%20Lean%20Test.pdf