

EGT AND COMBUSTION ANALYSIS

By Al Hundere

In A Nutshell



Precision Products For Piston-Powered Aircraft

Introduction to ALCOR



About ALCOR



In 1957, an engineer and pilot named Al Hundere recognized the growing need for bringing innovative and reliable products to the newly-developing aviation industry. Founders Al and Alice Hundere, originally established Alcor (AL's CORporation) to

conduct research and testing of gas turbine lubricants and fuels. Al and Alice's son, Michael, continues the family tradition of bringing high quality aviation products to satisfied customers worldwide.

About The Nutshell

For the purpose of this document, the single sensor EGT system is referred to as an EGT Mixture Control Indicator and the multi-sensor EGT Indicator (exhaust sensor for each cylinder) is called a Combustion Analyzer.

Although the goal is to control the mixture of the leanest cylinder, a pilot faces the dilemma of not knowing for sure which cylinder is the leanest.

Therefore, excess fuel is used to compensate for this uncertainty. The Combustion Analyzer solves this dilemma, permitting optimum mixture control by being able to "see" the mixture distribution allowing the leanest cylinder to be always selected for mixture control.

A much greater advantage of the Combustion Analyzer is its ability to act as a trouble detector. Proper understanding and use of the multi-sensor EGT unit alerts a pilot to engine trouble so that corrective action can be taken to prevent emergencies and minimize engine damage.

It is our goal to present the EGT method of mixture control and combustion analysis so that pilots can derive maximum benefits from their EGT systems. These benefits include not only economy and safety, but the greater peace of mind that comes from increased engine reliability.

If you have additional questions please contact us at **210-349-6491** or visit our web site at **www.alcorinc.com**.



Contact ALCOR
800-FLI-SAFE
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For the Engine Manufacturers' specific recommendations, see **Continental's Service Bulletin M89-18 and **Lycoming's Bulletin # 1094D**. The recommendations given in this text are intended only to supplement the leaning instructions given in the Airplane Owner's Manual and the Engine Operator's Manual and not as replacements thereof.*

Understanding The Hardware

Figure 1 shows the four strokes of the four-cycle piston engine. It is the quantity of fuel and air inducted in the first stroke, or intake stroke, that determines the combustion temperature after the second stroke, the power generated in the third stroke, and the exhaust temperature for the fourth stroke.

Figure 2 shows how the throttle controls the flow of air and how the mixture control lever adjusts

the fuel flow. The ratio of fuel to air, which we call "mixture," determines the combustion temperature. That in turn, is directly related to the exhaust temperature. An engine's fuel requirements are dependent on the mixture and not the fuel flow; therefore, a fuel flow indicator, no matter how accurate, does not define the fuel requirements as accurately as the EGT method of mixture control. Fuel is added to the air flowing through the engine

carburetor or induction system for the purpose of generating heat. A piston engine, like any other aircraft engine, is a heat engine. If fuel were added only to obtain heat, then mixture control would be greatly simplified. However, a secondary function of the fuel to a piston engine is to provide cooling when needed.

The common method of measuring EGT is shown in **Figure 2**. A

very small sensor* inserted into the exhaust is wired to a special millivolt instrument in the panel so very small changes in EGT can be easily observed. The instrument pointer does not start moving until the temperature is about 1200°F, and is full scale at about 1700°F.

Figure 3 shows a typical instrument and sensor.

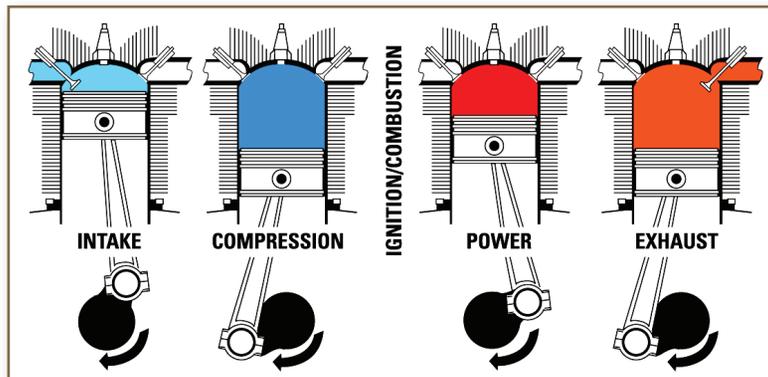


FIG. 1

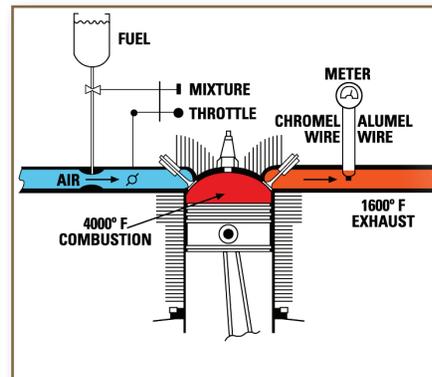
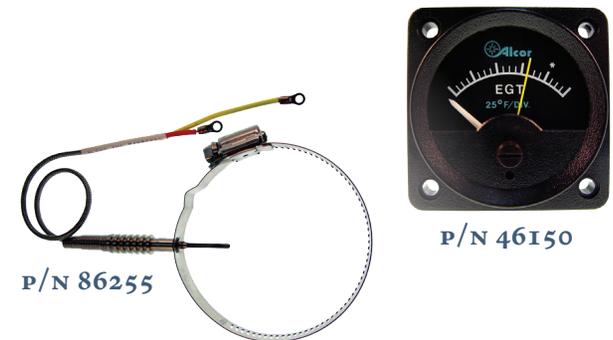


FIG. 2



*ALCOR's EGT Sensor tips are the smallest in the industry, producing the fastest response time. ALCOR offers the best warranty in the industry (see www.alcorinc.com).

“Peak EGT” Is The Key



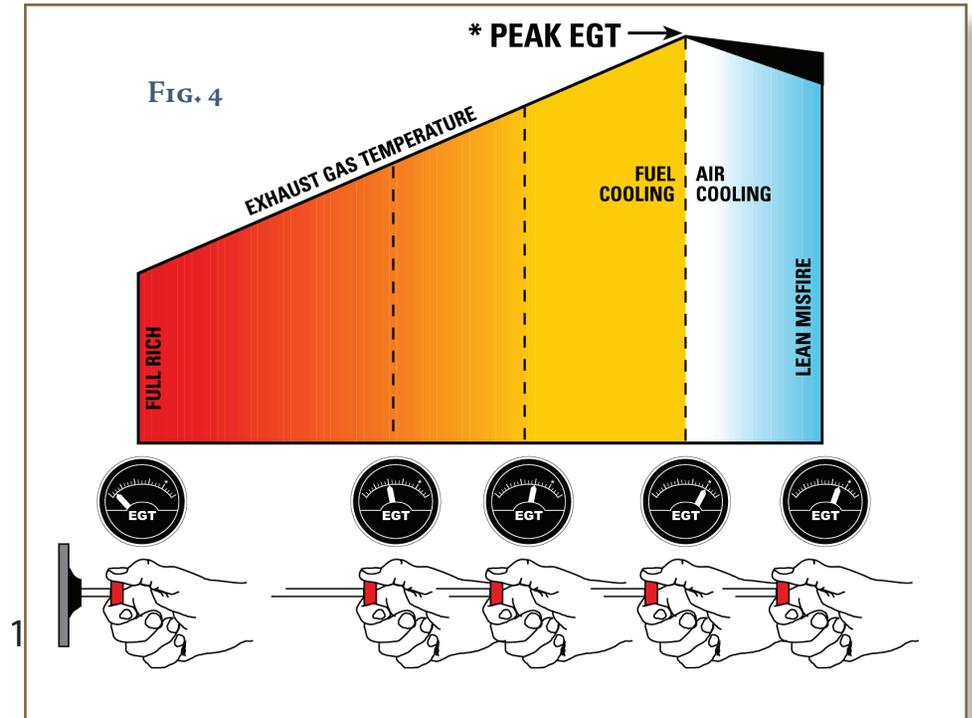
What is so special about EGT for mixture control?

The novelty of the EGT method is in observing the peak temperature while simultaneously adjusting the mixture, eliminating the need for a fuel flow indicator and plotting a curve. This method requires a fast-response EGT sensor and indicator (as shown in Figure 3), sensitive enough that very small changes in EGT can readily be observed as they occur.

Figure 4 shows how EGT changes with mixture leaning. As the mixture is leaned from the full rich position, the EGT increases (as shown) as the amount of excess fuel is decreased. The less excess fuel, the greater the EGT. While excess fuel is present, the EGT increases with mixture leaning until no excess fuel exists.

At this point “**peak EGT**” occurs (as shown in **Figure 4**). Further leaning decreases the EGT (as shown) as a result of cooling from the excess air.

“Peak EGT” is the key to the EGT method. Excess fuel and excess air cause cooling of the exhaust. Peak EGT occurs when there is no excess air or fuel. The black band shown in **Figure 4** for the lean side of peak EGT indicates how engines vary greatly in their ability to burn lean mixtures. Operating on the lean side of peak impacts the degree of leaning possible. Poor lean mixture combustion can cause peak to disappear or become very flat. Also, a secondary peak can develop with poor lean mixture combustion. This should be ignored in setting the mixture.



REMEMBER: When using the EGT method of mixture control, all mixture settings are made relative to peak EGT.

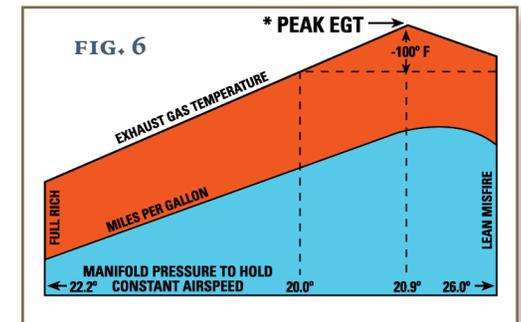
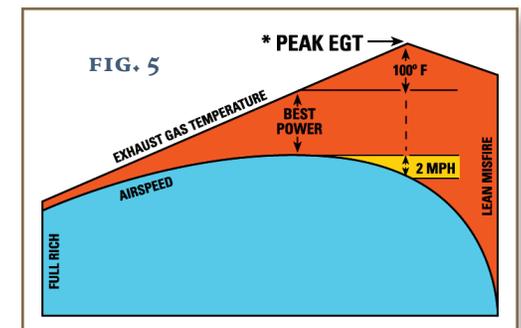
Maximum Range at Cruise Power

At cruise power settings, **peak EGT** is normally considered optimum because it gives maximum fuel efficiency—that is maximum energy output per unit of fuel. A mixture *leaner than peak* increases aircraft range as a result of a decrease in power and NOT from efficiency of fuel use. **Figure 5** shows the effect of mixture leaning on aircraft airspeed, holding rpm and manifold pressure constant. As shown, the maximum airspeed or “best power” mixture is obtained when the mixture is set to give an EGT approximately 100°F below peak EGT on the rich side. This is at the expense of a 15% increase in fuel consumption.

As the mixture is leaned from best power mixture to peak EGT, the air-speed decreases 2 mph and decreases rapidly with further leaning. Since aircraft range is controlled by both mixture setting and power setting, the effect of mixture setting on range is best illustrated under conditions where the power is held constant (constant airspeed) by varying the manifold pressure as the mixture is changed (as shown in Figure 6). Note that going leaner than peak EGT does not increase the miles per gallon significantly, but will require a higher manifold pressure to maintain

constant airspeed. For this reason, peak EGT is considered the optimum mixture for maximum range. Adding excess fuel for a slight gain in power or airspeed is only one reason for operating richer than peak EGT. If the cruise power setting is sufficiently high, then excess fuel is needed for cooling; at low cruise power settings there is no benefit from the use of excess fuel unless it is to compensate for the mixture distribution problem of a multi-cylinder engine. Both these will be discussed in the next section.

ALCOR has seen no indication that the TBO (time between overhauls) of any modern aircraft engine is shortened by operating at peak EGT mixture setting up to 65% power, provided that the leanest cylinder is truly selected and used for mixture control.



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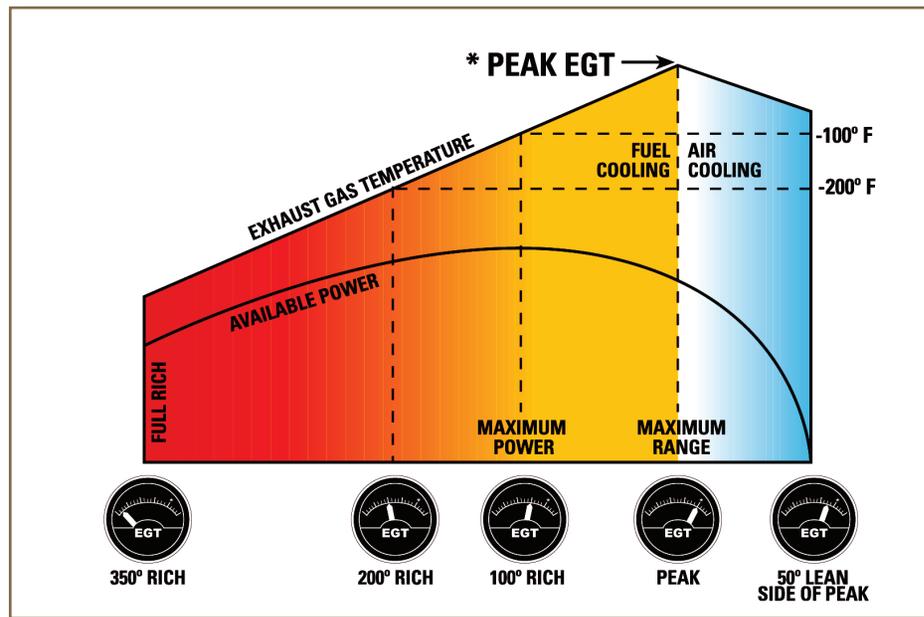
Economical Considerations



The economical considerations of mixture control over 100 hours of operation.



The economic aspect of mixture leaning is illustrated in **Figure 7**. **Figure 7** presents actual flight test data from a typical single engine aircraft at 10,000 feet. The engine is an O-470 with a power setting of 65%. Note that \$5,200 is spent on excess fuel in 100 hours when best power mixture is used rather than peak EGT. This is considered with fuel at \$4.50/gal.*



TAS
GPH
MPG
100 Hour Fuel Cost
Cost Of Excess Fuel
Cost of Excess Fuel Per Hour

350° RICH
17.8
8.7
\$8,010
\$3,060
\$13.60/hr

200° RICH
15.2
10.6
\$6,480
\$1,890
\$8.40/hr

100° RICH
13.2
12.3
\$5,940
\$990
\$4.40/hr

Peak
11
14.5
\$4,950
0.0
Maximum Economy

50° Lean Side Of Peak
GPH
MPG
-
-
Precautions should be taken to prevent engine damage

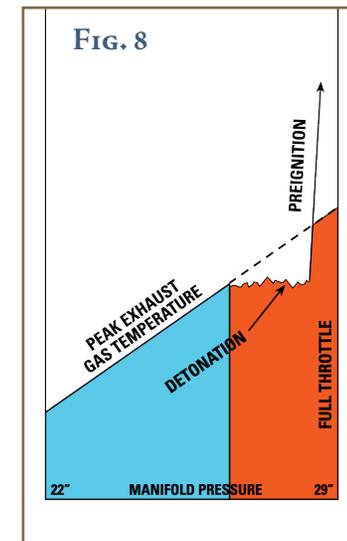
*Cost per gallon of \$4.50 may vary depending on regional FBO, location and availability.

FIG. 7

Peak EGT and Power Increase

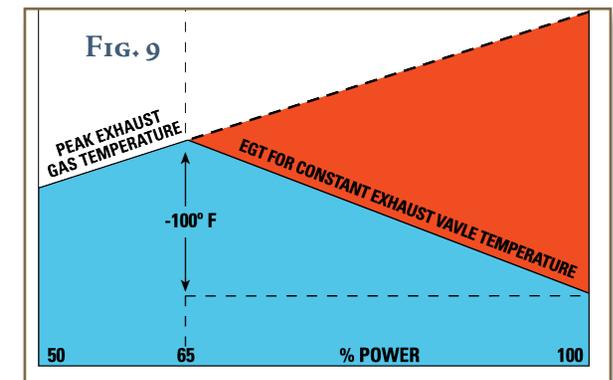
As an example, assume an average unsupercharged engine that has a take-off manifold pressure of 29.0" and that the mixture is maintained at peak EGT as the throttle is slowly moved from cruise (22.0") to full throttle (29.0" manifold pressure). The resulting increased temperature of the exhaust valve and/or spark plug electrode would cause pre-ignition, the onset of which would be hastened by detonation. Pre-ignition of this type is destructive and engine failure can occur in a matter of seconds. **Figure 8** illustrates how such a failure would be reflected in the EGT; a typical failure from pre-ignition is shown in the photograph below. Excess fuel must be used

for cooling at the higher power settings to keep from exceeding maximum allowable temperatures. The exhaust valve is usually the most critical with respect to excessive temperatures. When the mixture is enriched at powers above 65% to maintain constant exhaust valve temperature, the EGT versus power curve is as shown in **Figure 9**. As illustrated, the EGT at 100% power needs to be 100°F lower than peak EGT at 65% if the exhaust valve is to be maintained at the same temperature as it is at peak EGT for 65% power.



ALCOR recommends that the peak EGT at 65% power be considered the maximum allowable EGT NEVER TO EXCEED.

WARNING! DO NOT LEAN THE MIXTURE TO "PEAK EGT" ABOVE NORMAL CRUISE POWER SETTINGS



Always Keep it In The Green



The dial[✦] presentation shown in **Figure 10** is intended to make all the preceding information easier and simpler for the pilot. The reference mark (*) is peak EGT at 65% power and, with such calibration, all the pilot has to remember is to keep the EGT in the “green” at all times—takeoff, climb, cruise and descent.

Most EGT analog dials have relative scales rather than colored range markings as shown in **Figure 10**. This makes it necessary to keep a mental picture of these markings and remember that the reference point (*) is peak EGT at 65% power under fixed operating conditions such as 2300 rpm and the altitude where full throttle produces 65% power. Peak EGT will occur above or below the reference mark for cruise power settings which vary from that used for calibration. The blue area in **Figure 10** indicates the normal EGT during ground run-up, say 1700 rpm. This can be checked at sea-level, full-rich, ground run-up, and can be used for leaning during ground run-up prior to take off from high altitude airports. **Why not provide a specific mark for the correct mixture during takeoff and climb, like the center of the green arc?** The reason is that such a mark would be valid only on a day when the outside air temperature is average, say 70°F. During takeoff and climb the cylinder head temperature must be considered in mixture leaning. On a very hot day, more than the normal amount of fuel must be



FIG. 10

used for engine cooling so that the EGT reading needs to be decreased to control CHT. Similarly, on a very cold day, the EGT can be higher because less fuel is needed for cooling, as illustrated in **Figure 11**.

For cruise, using the **Figure 10** dial presentation, all one needs to remember is to lean to peak EGT for best fuel economy unless this puts the EGT into the yellow arc, in which case the mixture should be enriched sufficiently to keep the EGT in the green.

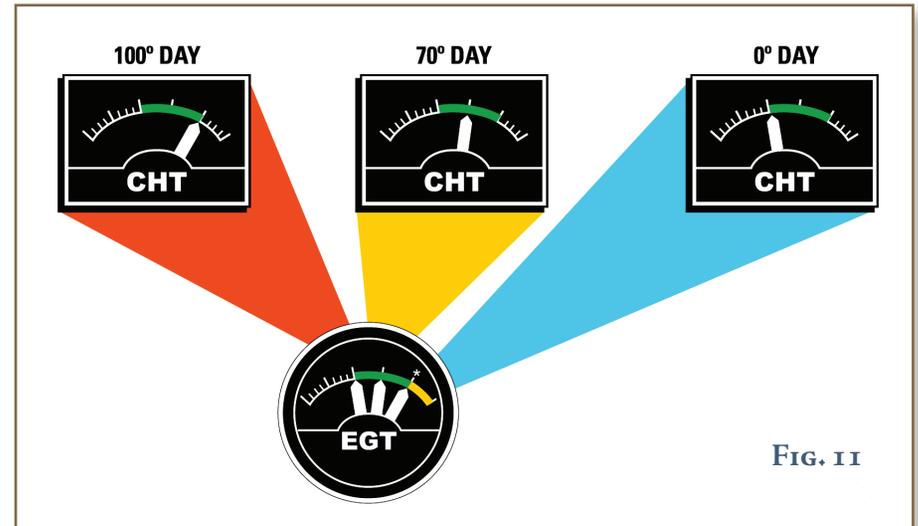


FIG. 11

[✦] Whether analog or digital, the method is still the same.

Custom and standard color dials available from ALCOR



No Such Thing As The Leanest Cylinder

The term “mixture distribution” means the uniformity by which the fuel distributes itself with the air being inducted into the engine through the carburetor or the air intake system of a fuel injection engine

Perfect mixture distribution is where the quantity of fuel to each cylinder is the same percentage of air ingested into each. In the preceding sections, an engine with perfect mixture distribution is assumed, which is practically non-existent. The leanest cylinder (one receiving the lowest percentage of fuel) should be selected for mixture control, as engine manufacturers have recognized by recommending the location of the EGT sensor in the exhaust of the leanest cylinder. Excess fuel provides a margin of safety so one can say that the leanest cylinder has the lowest margin of safety! The mixture distribution problem is significant as **there is no such thing as THE leanest cylinder under all operating conditions**, shown by examining some typical engine mixture distribution patterns. Even with an engine that approaches perfect mixture distribution, any one cylinder can suddenly become much leaner through a simple malfunction.

Figure 12 represents a typical carburetor engine. At each altitude the leanest cylinder was leaned to peak EGT after setting of 65% power. At 9000 feet full throttle was reached and then the power decreased with further increase in altitude. **Note: cylinder No. 1 was leanest part of the time (highest EGT) and No. 3 was leanest at full**

throttle; note further that the mixture distribution is best just before reaching full throttle.

Figure 13 represents a fuel injection engine. A common misconception is that fuel injection engines have a perfect mixture distribution. Any cylinder of a fuel injection engine can suddenly become the leanest due to a restriction developing, like a piece of dirt getting into the fuel nozzle orifice, or from residue build up.

How can one be sure that the cylinder with the highest EGT is truly the leanest cylinder?

Figure 14 shows the mixture distribution pattern of a four-cylinder engine with each cylinder in the same condition and receiving the same airflow, all cylinders reaching peak at exactly the same EGT. The leanest cylinder has the highest fuel flow, as shown. This situation is not always the case, as shown in **Figure 15** where all cylinders peak at the same fuel flows as in **Figure 14**, but the leanest cylinder no longer has the highest EGT. Anytime it is suspected that another cylinder other than the one with the highest EGT is the leanest, the simplest procedure for verification is to lean the cylinder with the highest EGT to peak, turn the selector switch to the other cylinder in question and then enrich the mixture just enough to see some pointer travel. If the EGT increases, it is leaner, and was already on the lean side of peak.

FIG. 12

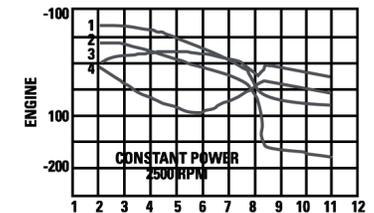


FIG. 13

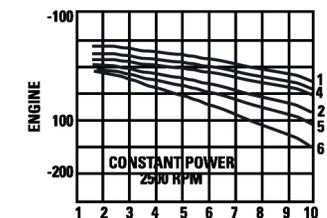


FIG. 14

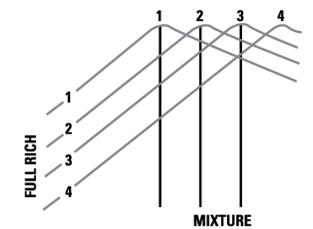
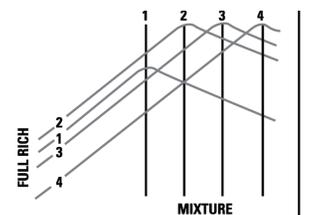


FIG. 15



What Is The Solution To The Mixture Distribution Problem?

One solution is to enrich the mixture to drop the EGT a given amount, say 50°F, to compensate. The amount of compensation will depend on whether the exhaust sensor is sensing one cylinder, so-called "leanest cylinder" or a cluster of cylinders such as 1, 3, and 5. For example, in Continental's Service Bulletin M89-18 it states, "If the unit (exhaust sensor) is located in the exhaust system sensing multiple cylinders, operation further from peak is required to avoid any one cylinder running too lean." The obvious disadvantage of this method of compensation is loss of fuel economy. As was shown by **Figure 7**, a 100°F enrichment for compensation costs \$5,940 in 100 hours for an aircraft with an O-470 engine, or half of this, \$2,970, for the 50°F enrichment from peak recommended by Continental. Additionally, the "over rich" cylinders are prone to develop combustion chamber deposits, plug fouling, and other detrimental effects from "over rich" operation.



P/N 46150
EGT Meter

For more information please visit our web site at www.alcorinc.com

The EGT Analyzer System

THE BEST SOLUTION is to monitor each cylinder so that the leanest cylinder can be pinpointed even as it may change. In cases where poor mixture distribution is noted, carburetor heat, alternate air, or throttle position can be adjusted to improve distribution and "fine tune" the mixture setting for maximum range and longer engine life. This can only be done with any degree of accuracy or safety by monitoring each cylinder with an EGT Analyzer System.

The equipment involved for the EGT Analyzer System is the same as for the EGT Mixture Control Indicator with added exhaust sensors, one for each cylinder, and a selector switch which can be incorporated with the instrument. An Alcor UCS Switch may be installed with Alcor's EGT Meter to monitor each cylinder



P/N 80827
Universal Cylinder Selector Switch

Trouble is a Reading in the Yellow

EGT and Combustion Analysis can be quite simple. Although most engine problems are best diagnosed with EGT, there are certain ones that can be detected most readily by an increase in CHT (cylinder head temperature); for example, a cracked cylinder head, or engine baffling problems. For this reason, some pilots prefer EGT/CHT Analyzers.

The first sign of trouble shows up as an indication either higher or lower than normal. When the EGT increases as shown, enrich the mixture if possible to compensate until you land and find a mechanic. You may prefer, however, from the standpoint of safety and peace of mind (not to mention reduced mechanic's charges), to be your own "engine doctor" by pinpointing the cause of the trouble before landing.



Simply remember to select the leanest cylinder, normally the one with the highest EGT for all mixture control settings, and then "scan" the other cylinders when convenient or when there is any concern for their health, such as a "feel" of roughness. Rely on Alcor's EGT/CHT to monitor your engine and minimize fuel and maintenance costs.

See Page 11 for "Combustion Analyzer Trouble Shooting Guide"



Combustion Analyzer Troubleshooting Guide

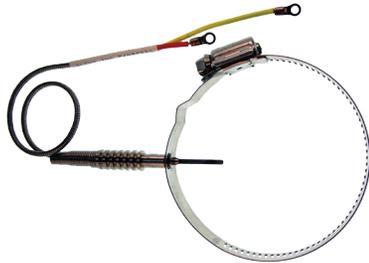


EGT	Symptom	Probable Cause	Recommended Action
	75° -100° rise for one cylinder.	SPARK PLUG NOT FIRING due to fouling, faulty plug, lead, or distributor.	1. Enrich mixture to return EGT to normal for cylinder with highest EGT. 2. Go to single mag operation. When mag firing bad plug is selected, EGT will drop suddenly, defining plug is not firing.
	75°-100° rise for ALL cylinders.	One magneto not operating.	Enrich mixture to return EGT to normal.
	Increase or decrease, especially after ignition system maintenance.	Improper timing—increase in EGT means retard- ed ignition. Decrease means advanced ignition	Check EGT rise for each mag to determine any uneven timing.
	Loss of peak EGT.	Poor ignition or vapor in fuel injection system.	Have magneto tested.
	Decrease in EGT for ALL cylinders.	Decrease in total airflow—carburetor ice or induc- tion ice.	Check for change in manifold pressure.
	Decrease in EGT for ONE cylinder.	Intake valve not opening fully—faulty valve lifter.	Have valve lift checked.
	Decrease in EGT for ONE cylinder.	Scored cylinder or broken ring to cause low com- pression (EGT may increase due to plug fouling from oil consumption).	1. Go to single mag operation to check for plug fouling. 2. Have compression checked.
	Slow rise in EGT.	Burned exhaust valve.	Have compression checked.
	Decrease in peak and flat.	Detonation—usually the result of 80 octane fuel in 100 octane engine.	Enrich mixture, reduce power and relean mixture. Repeat to find power setting where normal peak is obtained or run rich
	Sudden off scale rise for any cylinder.	PREIGNITION.	During take-off—abort if possible. Go to full rich and reduce power if excess power is available. During cruise—cut throttle back quickly and re- open until EGT returns to normal. If it does not, reduce power to eliminate preignition.
	Any EGT decrease.	If none of the above causes is evident, suspect a low reading sensor or faulty connection.	Have calibration checked with ALCAL System Tester.
	Any increase in EGT	TROUBLE - because of malfunction of sensor, lead or instrument will cause a decrease	

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Alcor EGT/CHT sensors are legendary in the aviation community for quality and accurate performance.



Clamp Sensor
Alcor's most popular design available in Type K (grounded and ungrounded) and Type E (grounded).



Gasket Sensor
Available in Type J and K (grounded) and fits under various size spark plugs.



Screw-In Sensor
Available in Type K (grounded and ungrounded) and Type E (grounded). Thread options available include 1/8" NPT, 1/4" NPT and 7/16" - 20.



Bayonet Cylinder Sensor
Available in Type J and K (grounded).

Fuel Treatment

TCP ELIMINATES SPARK PLUG FOULING

TCP (Tricresyl Phosphate) Fuel Treatment is the only FAA Approved product of its type and is only available from Alcor. Since the introduction of 100LL as the main fuel for low-compression engines, Alcor has been a leader in providing pilots a fuel treatment that eliminates lead before it can cause fouling. A simple one-shot treatment with every fill-up prevents lead build-up on spark plugs and valves. Rely on the one-and-only Alcor TCP Fuel Treatment for a cleaner and smoother-running engine!

Note: TCP not to be carried aboard aircraft.



Instruments

Contact Alcor for information on customizing your instruments. A range of dial designs and internal lighting are available.

Customize Your ALCOR Instruments

Lean your engine the Alcor way with an EGT or CHT indicator for maximum range and peak performance. Our indicators are relied upon by pilots to determine how lean or rich the engine is running, save money on fuel consumption, detect engine problems and reduce wear and tear on aircraft engines.



Test Equipment

The ALCAL 2000 is the most affordable test system available. It accurately calibrates and troubleshoots EGT/CHT/TIT, Type K, J and E systems. The tester simulates thermocouple output millivolts up to 1750°F for EGT and TIT systems and 600°F for CHT systems. Battery powered, it's portable, durable Pelican case permits use on the ramp or in the shop.



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