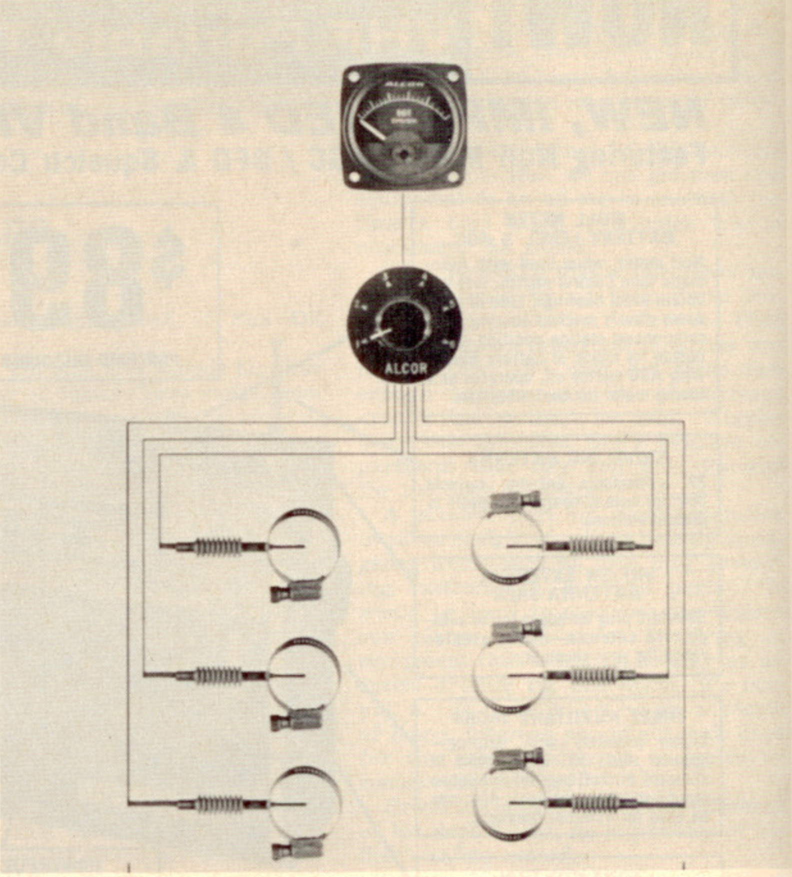
FIGURE 1: Direct switching EGT engine analyzer for six-cylinder engine



Analyzing

If a pilot devoted a fraction of the time he spends being concerned about the health of his engine to diagnosing possible troubles and taking corrective action, he could greatly reduce the chance of engine failure as well as the need for being concerned. Being able to "see" what is going on inside your powerplant produces a peace of mind that increases the joy of flying.

An instrument that gives "inside engine vision" to detect trouble during operation is called an engine analyzer. To be effective, an engine analyzer must be simple enough for the average pilot to read the indications readily.

The first aircraft engine analyzer was introduced about 18 years ago and detected engine trouble by observing the secondary ignition pattern on an oscilloscope (television tube). Although it found extensive use with the airlines and the military services, it was too costly and complicated for use on most general aviation aircraft. It cost as much as a small airplane and required much training and skill in interpreting the signals.

With the introduction of the exhaust gas temperature method of mixture control, pilots discovered that an EGT indicator is also a trouble detector. This resulted in a demand for more than one exhaust probe per engine, one for each bank or one for each cylinder. With a probe for each cylinder, the EGT of each cylinder can be read individually. This constitutes an effective system for general aviation, and the purpose of this article is to describe the design and application of this type of engine analyzer.

Figure 1 illustrates an engine analyzer for a single six-cylinder engine aircraft. When the selector switch is in the number one position it gives the EGT of cylinder number 1, in the number two position it is reading the EGT of cylinder number 2, etc. For a twin, two single meters or a dual meter can be used and the selector switch can be two singles or one doubledeck.

An exhaust probe goes into the exhaust pipe from each cylinder, making from four to 36 probes required for single- and twin-engine aircraft, depending on the number of cylinders per engine. A lead wire is run from each probe to the selector switch mounted on the panel. For the larger twin-engine aircraft, where running the bundle of lead wires into the cabin presents a problem, a remote control selector switch or copper lead wires can be used. The latter requires, however, a compensator to correct for the copper-to-thermocouple wire junction so that accuracy of EGT readings is unaffected. Figure 2 shows installed on the firewall a remote control selector switch and a copper lead wire junction to give a double analyzer installation for comparative testing. The longer the leads required and the greater the number of cylinders, the more important the use of a remote-control selector switch or copper lead wires becomes.

Figure 3 shows a twin-engine analyzer installation using remote control selector switches. Each push of the button rotates the selector switch to the next cylinder. The selector switch rotates in numerical order of cylinder numbers. To define the cylinder, the button lights up when the selector switch is on the last cylinder.

The cost of an EGT engine analyzer for a four-cylinder, single-engine aircraft is as low as $189 and for a twin-engine aircraft with four-cylinder engines as little as $378.

Besides the advantage of being able to select the leanest cylinder for mixture control, there are three major returns from the investment in an EGT engine analyzer. First is safety and the economic return of being able to detect engine trouble so that corrective action can be taken expeditiously. In terms of dollars, the reduction in maintenance cost plus the value of reduced downtime can easily equal the cost of an engine analyzer in a few hundred hours.

The second return is the increased performance that can result from reducing or correcting "engine illness"

FIGURE 2: Copper wire junction and remote control selector switch mounted on firewall of Cessna 210

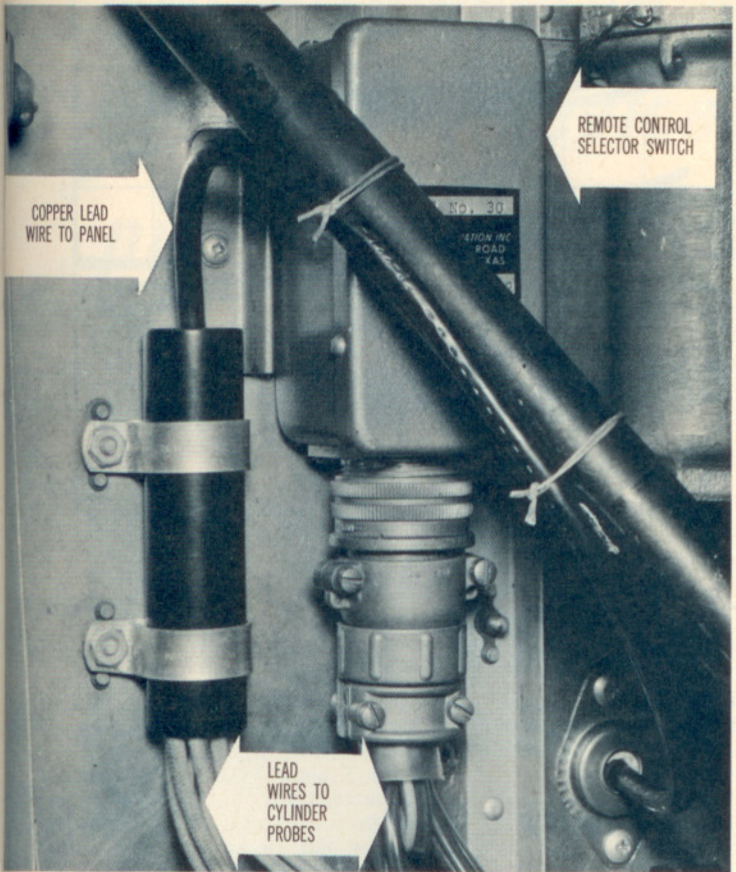
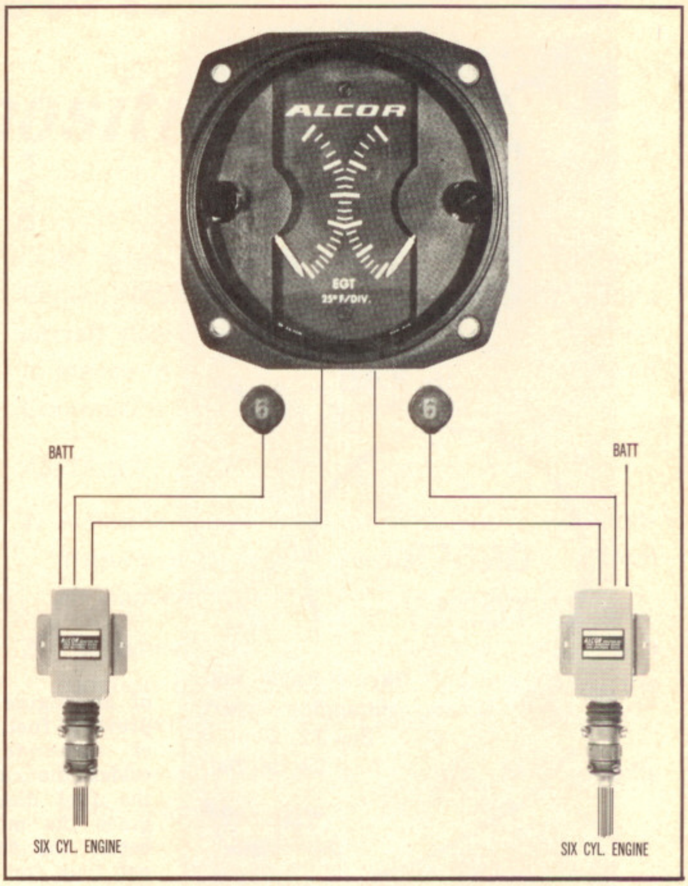


FIGURE 3: Remote control selector switch



Your Engine's Health

by AL HUNDERE • AOPA 42710

Manufacturer explains why engine trouble detection by exhaust gas temperature in-flight analysis can mean more economical and pleasurable flying

that isn't engine trouble but which detracts from optimum performance, such as poor fuel-air distribution that can reduce range 10% or more. Third, but not least, is the priceless peace of mind of knowing that everything is shipshape, which is usually the case with our modern engines.

Use of an EGT engine analyzer to determine fuel-air distribution to the individual cylinders is important from the standpoint of mixture leaning to obtain best performance as well as trouble detection. Figure 4 shows the fuel-air distribution of an O-470 engine. For each altitude the leanest cylinder was leaned to peak EGT. The fuel distribution shown is good for a carburetor engine. Note that the right bank of cylinders, 1-3-5, is the leanest and 2-4-6 the richest. Note also that cylinder number 1 is leanest at all altitudes. Throttle opening increases with altitude, being full-in above 6,500 feet.

Data obtained from other O-470 engines have shown that cylinder number 1 is not the leanest cylinder at all throttle settings. In fact, at part throttle for some O-470 engines, the number 1 cylinder is rich-running.

For most carburetor engines the leanest cylinder changes in going from part to full throttle, as shown in Figure 5 for an O-360 engine. Note that cylinder number 1 is leanest at part throttle and number 3 is leanest at full throttle. Again, the leanest cylinder was leaned to peak EGT at each altitude. In gathering data for this article, fuel distribution patterns were obtained on four O-360-AIA engines. No two distribution patterns were the same, even though the number 1 cylinder was always the leanest at part throttle. The most interesting thing to note from Figure 5 is the great change in fuel-air distribution as the throttle reaches the full-in position at 9,000 feet. This same characteristic was found for all of the four O-360 engines tested.

It was also interesting to find that the amount the throttle had to be closed to obtain this improvement in fuel distribution is so small that the change in manifold pressure could usually not be detected and at the most, it was only a tenth of an inch.

Another increased range advantage

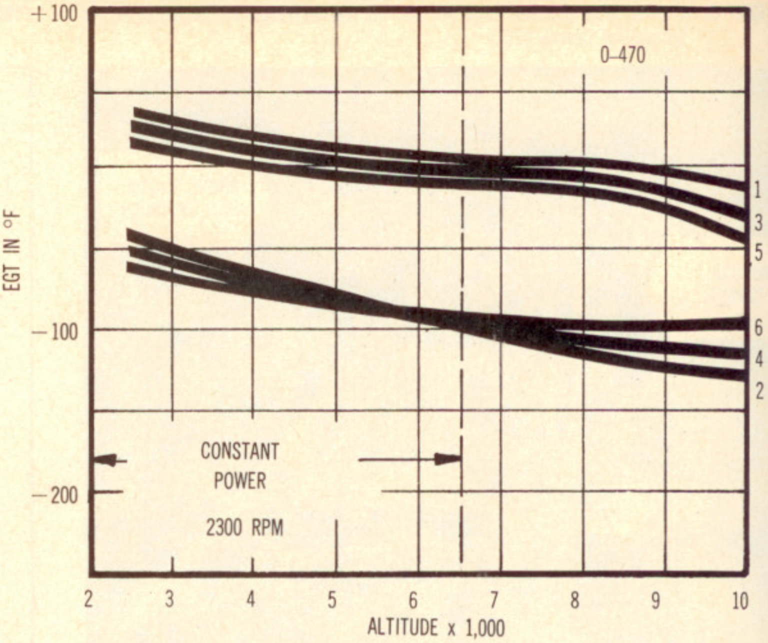


FIGURE 4: Fuel-air distribution of 0-470 engine

of an engine analyzer is that of improving fuel distribution by the use of carburetor heat. Normally, the colder the carburetor air, the poorer the fuel distribution. For some engines the more carburetor heat, the better the fuel distribution. This is not true for other engines where the change in air flow pattern by the carburetor heat door can change the air flow pattern to adversely affect the fuel distribution. Figure 6 shows such a case. Note that the fuel-air distribution was greatly improved by some carburetor heat, but at full hot, distribution was poorer than in full cold position.

So much for the fuel-air distribution of carburetor engines. How about fuel injection engines? It is commonly thought that fuel injection engines have perfect fuel distribution. This is not the case for the vast majority of present day fuel injection engines.

Figure 7 shows the fuel-air distribution pattern for one IO-470 engine. Again, for each altitude the mixture was leaned out to peak EGT for the leanest cylinder. Note that the maximum spread in EGT between the leanest and richest cylinders is about 125°F. This means that when the leanest cylinder is at peak, the richest is richer than best power. This spread between the richest and leanest cylinders can double on an extremely cold day—say, mid-January in the north country.

What is the explanation for all cylinders of a fuel injection engine not receiving the same amount of fuel?

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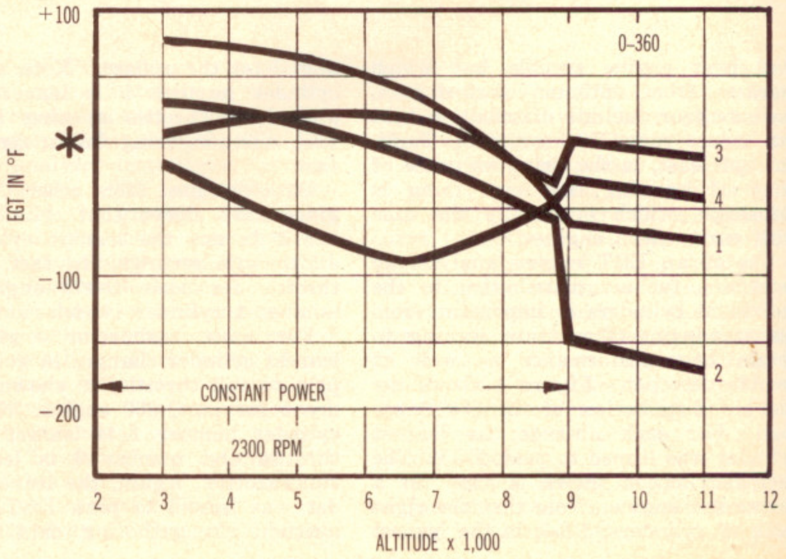
FIGURE 5: Fuel-air distribution of 0-360 engine



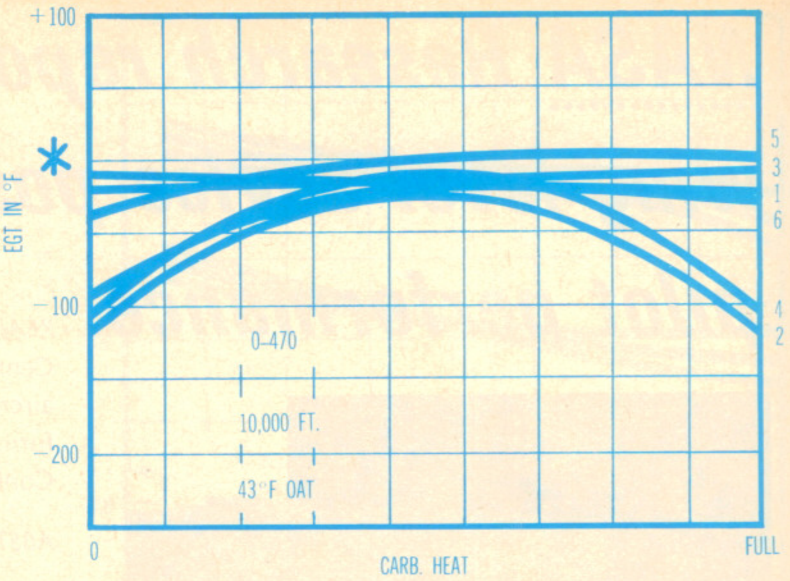


FIGURE 6: Effect of carburetor heat on fuel-air distribution

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It's because all the fuel injected into the port of the back cylinders does not end up going into these cylinders. Fuel is injected continuously and only drawn into the cylinder 25% of the time. During the time the fuel is injected but is not flowing into the cylinder, it collects in the intake pipe and heavy ends flow down to the common intake pipe and a good part can end up flowing to the front cylinders. Some of the newer engines, such as Continental's IO-360 (Cessna *Skymaster*) and Lycoming's TIO-541 (Mooney Mark 22), correct this by having intake pipes with downward flow, rather than upward.

In addition to the problem of cylinder-to-cylinder fuel-air distribution, there is the problem of cycle-to-cycle distribution. This means that the amount of fuel injected can vary with each intake stroke of the piston, although the average fuel flow to the engine remains constant. When poor cycle-to-cycle fuel distribution exists, the normal sharp peak in the EGT curve is not obtained as the mixture is leaned.

Mixture distribution is influenced by the volatility of the fuel in addition to the engine design and operating conditions, as has been shown. Obtaining good fuel-air distribution between cylinders is beneficial for two reasons. First, as explained above, is the resultant increased range through eliminating excess fuel going to the rich cylinders. The second benefit is the reduction in spark plug fouling.

Usually the richest running cylinders foul first. Of course, spark plug fouling is related also to the distribution of the lead and lead scavenger that are normal constituents of the fuel. The best way to check for spark plug fouling is with an engine analyzer in flight because in-flight indications of spark plug

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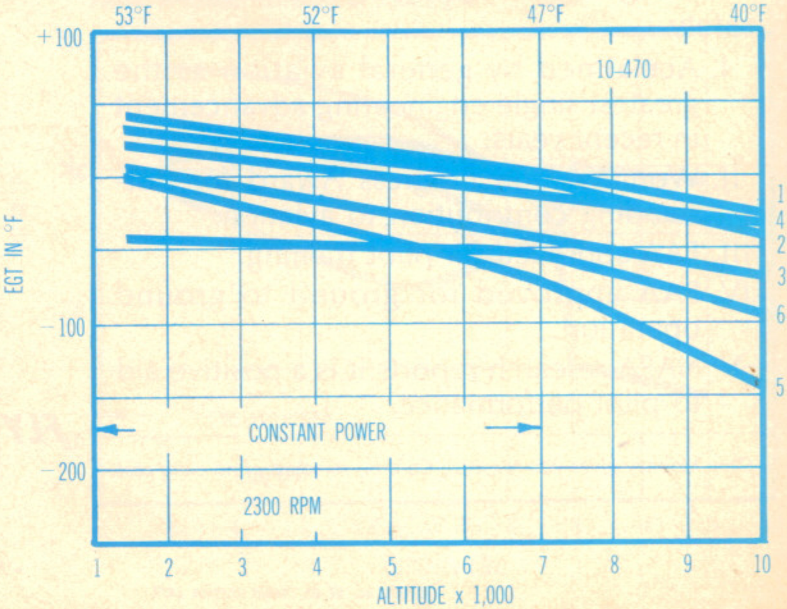
FIGURE 7: Fuel-air distribution of IO-470 engine



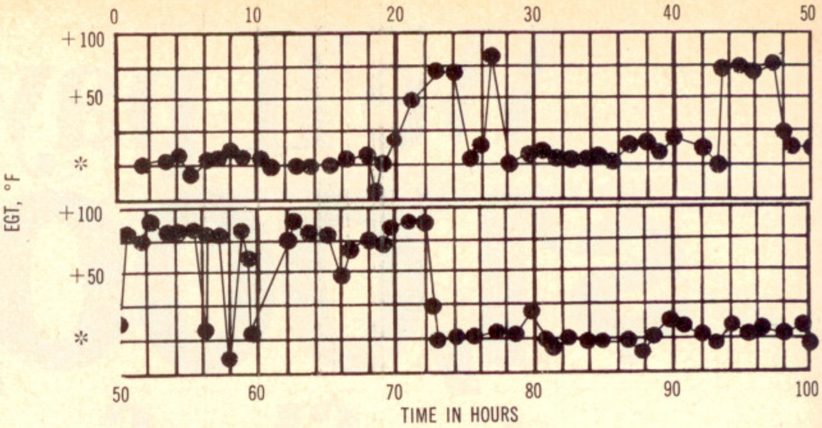


FIGURE 8: EGT from one cylinder of 0-470 engine under conditions of spark plug fouling

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fouling usually show up long before they can be found in a ground check.

This is illustrated in Figure 8, which is the EGT versus time pattern obtained for one cylinder of an 0-470 engine that was recently operated for nearly 1,000 hours under Air Force contract to study spark plug fouling. Operating conditions were cyclic, simulating a typical flight mission. An increase in EGT denotes spark plug fouling, and an increase of 75° to 100°F means a completely fouled plug. This same increase in EGT also occurs with the failure of a magneto and is observed for all cylinders.

Note that one plug was fouled out more than 20% of the time, but showed no fouling tendency during the last 27 hours. During the 100-hour period shown in Figure 8, the spark plugs were not touched and the fouling and unfouling indicated resulted from no outside influence.

A pilot using an engine analyzer can observe such fouling in flight and can take corrective action when noted, i.e., clear up by changing operating conditions or have plugs cleaned at the next stop.

Too advanced or too retarded a spark is reflected in a change in EGT. An advance in spark decreases EGT and a retard increases EGT. For example, if a change in EGT is noted after having engine work performed, it is a good indication that the spark timing was changed.

It should be remembered that the actual timing may be different than the set timing due to a faulty magneto. By switching to single magneto operation and noting the EGT for each magneto, a good comparison of respective actual timing can be made.

Figure 9 gives a summary of engine troubles that can be detected by EGT and the resultant change in EGT.

So far, the first five items have been covered. Poor ignition (item six), such as a low magneto output voltage, can cause poor lean mixture burning characteristics. For example, an ALCOR Mixture Control Indicator customer complained that his indicator did not work at altitude because above 15,000 feet the EGT did not peak. He blamed it on his ALCOR Indicator, although he had a normal peak at low altitudes. After having his ignition system overhauled, he obtained a normal peak at high altitudes.

An increase in EGT doesn't always mean ignition trouble. However, the first thing to do when an increase in EGT is noted is to go to single magneto operation and to check the EGT for each cylinder to determine if one plug has stopped firing. If both spark plugs are firing, then the two most likely causes for an increased EGT are exhaust valve leakage and preignition.

Preignition causes a rapid increase in EGT whereas the increase with exhaust valve leakage can be very gradual. Figure 10 shows this comparison, illustrating what happens to the EGT of cylinder number 2 with the occurrence of preignition and also the change in the curve if valve leakage occurred rather than preignition.

High EGT on one cylinder in a fuel injection engine during full power operation, such as takeoff, might mean a fouled injector, causing that cylinder to lean out. During cruise this would show up as an abnormally lean cylinder. Low EGT at peak usually means either low

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1. Poor fuel distribution	Comparison
2. Spark plug fouling	↑ 75–100°F
3. Magneto failure	↑ 75–100°F (all cylinders)
4. Too advanced spark	↓
5. Too retarded spark	↑
6. Poor ignition	No peak or abnormal peak
7. Exhaust valve leakage	↑ Continually increasing
8. Preignition	↑ 100–1,000°F
9. Cylinder too lean (fuel-injection)	↑ Take-off
10. Low air flow to cylinder	Comparison at peak
11. Detonation	Flat peak

FIGURE 9: Engine troubles detected by EGT

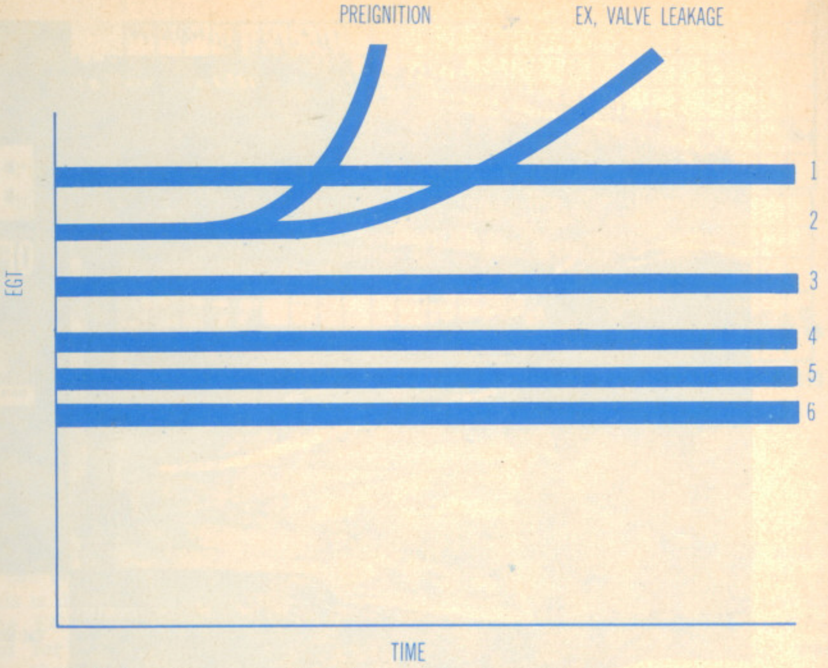

FIGURE 10: EGT change with preignition and exhaust valve leakage

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air flow to the cylinder or detonation. A restriction in the intake pipe or a malfunctioning valve will cause low air flow to the cylinder affected. For example, when I owned a Cessna 180 and had over 1,000 hours since overhaul, I had a cylinder that showed a gradually decreasing EGT at peak. When the drop reached better than 75°F, I switched exhaust probes to make sure that it wasn't a probe condition. It was not. The engine was torn down and it was found that the air flow to this cylinder had decreased greatly because of cam lobe wear, reducing the intake valve opening to about 50% of normal.

Detection of detonation by EGT has been reported by several ALCOR customers in our 17,000-plus installations. A *Bonanza* owner with an IO-470 engine reported that his indicator peaked out lower than normal and that the peak was broad. Being a thinking pilot, he switched fuel tanks—to the one that had no fuel added at the last refueling. Peak EGT was then normal. The detonation resulted from being refueled with 80 octane rather than 100 octane.

An Aero Commander owner with IGSO-540 engines reported encountering a broad peak. Since this was at high cruise power, it was suggested that he try a lower power. He found a normal peak EGT. A flat peak with reduced EGT means detonation when it is observed at high power but not when the power is reduced.

This is illustrated in Figure 11. Note that the cylinder head temperature increases when the EGT decreases. This is because there is an increase in the heat going into the cylinder head, thereby reducing the EGT.

If you are an average pilot, you may have concluded by now that an EGT engine analyzer is too complicated for you to use. This is not so. It is simple to use for protecting your engine even though you might know little or nothing about what the indications mean. During the past year a program was conducted with the Air Force to demonstrate the value of an engine analyzer in reducing engine failures. A U-3A (Cessna 310 with O-470 engines) was used for the program. The Air Force requested that instructions be made as simple as possible. To aid in this, a special dial was used as shown in Figure 12.

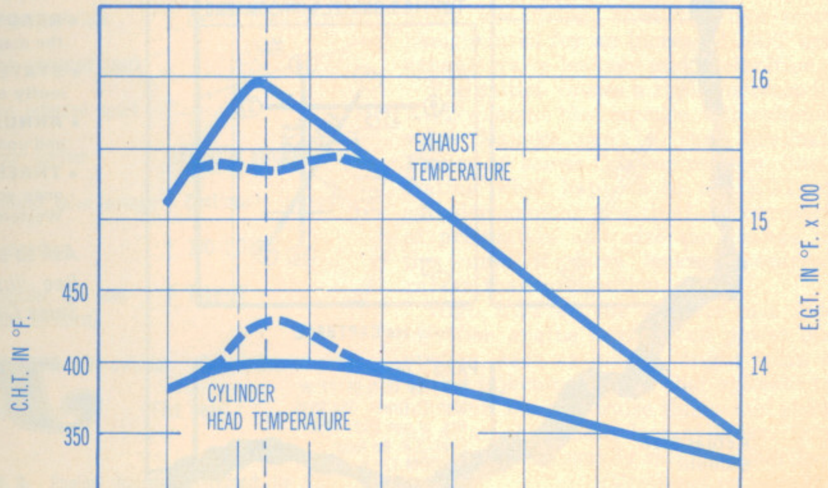
The arc above the asterisk (*) is red. The meter was calibrated so that the pointer is at the asterisk at peak EGT at 65% power at that altitude where the throttle is wide open (about 6,000 feet).

Instructions to the pilot were simply to select the cylinder with maximum EGT for mixture control and to monitor all cylinders at intervals. He was told that an EGT reading in the red for any cylinder indicated engine trouble and to enrich mixture and/or reduce power as required to keep EGT out of the red until the cause of the trouble could be determined.

This is all the pilot had to do to obtain protection from engine troubles. He was, of course, supplied information on diagnosing engine troubles such as contained is this article, but the understanding and application of the information is not required to obtain reasonable engine protection. All that is required is to keep the pointers out of the red.

The program demonstrated the value of an EGT engine analyzer in reducing engine failures. The Air Force was also pleased with the substantial reduction in fuel consumption and the reduction in spark plug fouling. As a result, the Air Force has requested the installation of EGT engine analyzers on all of their U-3 aircraft. ●

FIGURE 11: Effect of detonation on EGT and CHT



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Al Hundere, a frequent contributor to The PILOT, is president of ALCOR Aviation, Inc., San Antonio, Tex. This article was prepared at the request of AOPA to highlight the emergence of a new technological advance that may aid in making private flying safer and more popular.

FIGURE 12: New dial with red arc