EGT Systems – What do they do for you?

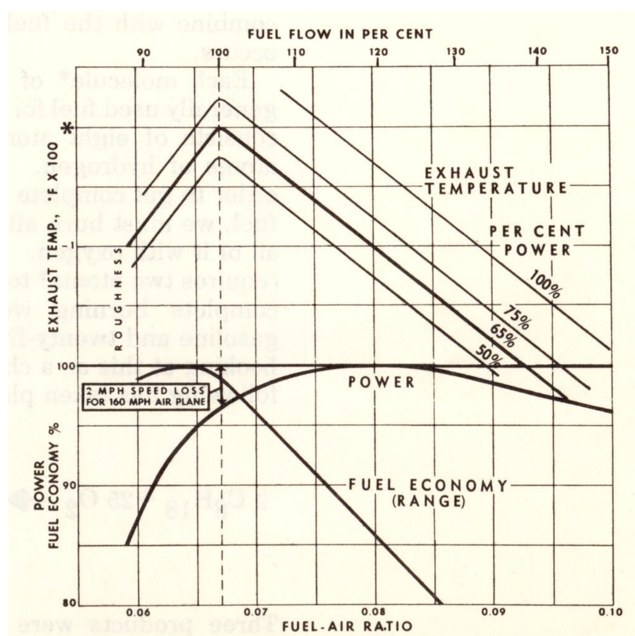
Wayne Pratt CFII

Most airplanes have a simple EGT gauge (Exhaust Gas Temperature) such as the one shown here. Most pilots know to lean the engine to peak EGT and back off 100°F, but what are you really doing and what does this mean to the engine and your fuel consumption.

EGT measurements came from experiments conducted during WW II that enabled aircrews to achieve the maximum possible range for their bombers.

Most aircraft have a single point EGT system installed in the exhaust port of the cylinder that the factory has determined that is normally expected to have the hottest EGT. What we mean by *single point* is that a single thermocouple temperature sensor is mounting intruding into the exhaust stream just outside the exhaust valve in the exhaust manifold of the cylinder being monitored. Multi-point systems have a thermocouple in the exhaust manifold for each cylinder.

A thermocouple generates a small voltage proportional to the temperature at the probe. Typical EGT at cruise run about 1500 °F. At this temperature the probe produces about 36 mv (.036 Volts). Digital EGT amplify this and display precise temperatures. Analog instruments, like the one shown above, read out the voltage directly with no calibration numbers.



The peak exhaust gas temperature provides a reference from which the desired fuel-air mixture ratio may be determined.

The chart at the right shows how the EGT varies with the ratio of fuel to air. This ratio is controlled directly by the aircrafts mixture control, usually the red knob. The first thing you should notice is that EGT reaches a peak value when the fuel to air ratio is .067. This means that for each pound of fuel consumed the engine is consuming 15 pounds of air. You might guess that this magic mixture ratio has a name. Chemists call it the stoichemetric mixture. In a stoichemetric mixture the mass of combustible fuel just matches the amount of oxidizer (oxygen) present.

When excess fuel is present the mixture is determined to be *rich*. When there is excess air the mixture is called *lean*. If you happen to be less technically inclined you might want to skip the next couple of paragraphs.

Fuel (avgas) weights 6 lb/gal and air weights .0763 lb/ft^3 under standard sea level conditions. This translates to .0102 lb/gal. This means the engine needs to use 8764 gal of sea level air for each gal of fuel.

To put that in perspective the Cessna 172SP as well as the DA-40 has a displacement of 360 in^3 or 1.6 gal. When it turns at 2500 RPM it draws in 1950 gal of air per minute (the engine type is 4 stroke, so only half of the revolutions bring in air). Ideally this is 19.8 lb/minute of air. But the air pumping efficiency of the engine is 75% so only about 14.8 lbs of air are actually going through the engine. For a stoichemetric mixture you need .99 lb/m of fuel to match up with the air. This translates to 9.9 gal/hr, which is about right for what we know from the POH.

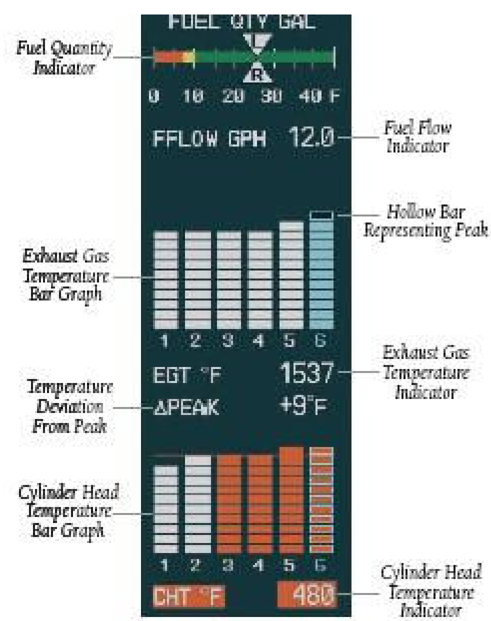
When you are operating on the *rich* side of peak EGT there is excess unburned fuel in the engine due to the fact that there is insufficient air to match up with the mass of fuel. In this case the unburned fuel carries heat away from the engine resulting in lower EGTs. When operating on the lean side of peak EGT there is insufficient fuel to match up with the air so there is less energy developed, therefore cooler temperatures.

Also notice on the graph that the peak EGT increases with increasing power up to the maximum power output for the engine. For most engines this will be around 1570 ^{o}F. So referencing your leaning point from the maximum (or peak) temperature has become the standard practice. Most often this is given be the manufacturers to be *Peak -100 ^{o}F*.

The engine power is also a function of EGT. Experimental results show that the maximum power is developed when the mixture is set to an EGT reading of **Peak EGT – 100 ^{o}F** at this temperature the fuel to air ratio is .083. At this setting you are consuming 26% more fuel per minute than at peak EGT. But, for that RPM/throttle setting the engine is producing the maximum possible power.

In the case of a single probe system this is the temperate of the exhaust gases at only that cylinder. What about the other cylinders? For carbureted engines the air and fuel is mixed as it passes through the carburetor and intake manifold. The fuel/air charge in each cylinder may be a little different, but the mixture will be pretty consistent. In fuel injected engines the fuel is injected directly into each cylinder through a small nozzle and mixed with the intake air during the compression stoke. For fuel injected engines the fuel/air ratio in each cylinder depends on how closely each injector nozzle is matched.

You usually find each cylinder peaks at a slight different fuel flow as you adjust the mixture control from *rich* to *lean* settings. Here is a picture from the *Lean Engine* page in a Garmin G1000 system. In this example, cylinder #6 has the hottest EGT. Adjusting the fuel flow so that the first cylinder to peak is



running 100 ^{o}F lean of assures that all the remaining cylinders are running on the rich side of peak.

There is an on-going argument about running general aviation piston engines at peak or even on the lean side of peak to conserve fuel. The old school argument is that you will burn the engine up. But does that make sense? The engine is operation at all the same temperatures as on the rich side of peak. The problem comes about with only a single probe you have no visibility as to what the temperatures are on the unmonitored cylinders.

But, carefully leaning the engine so that the hottest EGT is on the lean side of peak EGT and 50 ^{o}F below that peak EGT assures all cylinders are well below peak EGT. In this circumstance the engine is running at nearly the same temperatures as it was when running 100 ^{o}F below peak EGT on the rich side.

Look at the fuel benefits. The EGT Chart tells us the fuel air ratio will be about .055 – that's only 1 lb of fuel for 18 lbs of air, a 31% improvement over running at 100 ^{o}F rich of peak EGT on the rich side. The result will be a reduction in power of about 6% and a corresponding reduction in speed of 8 kts for a 130 kt airplane.

For the DA-40 (IO-260 engine) the nm/gal would increase from 14.4 to 17.4 nm/gal a 21% increase.

What is the influence of the EGT on CHT (cylinder head temperature). The heat of combustion heats the cylinders, and the residue from this we read as EGT. Each cylinder is cooled by airflow. The cylinder with the hottest EGT is not necessary the hottest cylinder when it comes to CHT. Typically one of the cylinders furthest aft will be the hottest just for the lack of airflow. But you can cool the front cylinders too quickly through a combination of low power (low EGT) and high speed – a lot of airflow. You can see that CHTs are certainly influenced by the EGTs so monitoring both, especially during extended climbs and descents is prudent.

In summary, EGT is a direct product of the combustion process. Understanding how it relates to fuel consumption and engine power for fuel management, aircraft range and endurance, and power plant management is essential for your safety and successful flight operations. If you are paying for the fuel and maintenance you will find out right away how well you understand EGT and CHT implications.