OPERATION INSTRUCTIONS FOR INSIGHT GEM 610C-001, G4-001 AND G4-002

DOCUMENT No. 070907

PLEASE READ INSTRUCTIONS COMPLETELY BEFORE PROCEEDING

INSTRUMENT CORP.

Box 122
Fort Erie
Ontario
L2A 5M6

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WARRANTY AND SERVICE

The Insight Instrument Corp. G-series GEM is warranted against defects in materials and workmanship for two years from date of purchase. Insight temperature probes are warranted for one year or one thousand (1000) hours which ever comes first. Insight will at its option repair or replace without charge those products that it finds defective. Insight will not be responsible for repairs required by improper installation, unauthorized maintenance or abuse. No other warranty is expressed or implied. Insight is not liable for consequential damages.

TECHNICAL SUPPORT

If you have difficulty installing or using a G-series GEM system, please read the GEM's installation manual and operating instructions. Every GEM system is shipped with complete instructions for installation and use. The answers to many technical questions can be found in this booklet, or the G-series GEM Installation Manual. Insight provides customer support free of charge for as long as you own the instrument. The Insight website (www.insightavionics.com) contains all the required documents for installing and operating a G-series GEM. If you can't find what you're looking for email us at:

G3techsupport@insightavionics.com

The Customer Service department accepts calls Monday through Friday between 9 am and 5 pm EST. Please have your instrument model number and serial number(s) ready when you call.

GEM FUEL TOTALIZER CAUTIONARY NOTICE

The Fuel Remaining display on the GEM is very useful but is not without limitations. Understand first that the factory fuel quantity gauges are the only instruments in the panel that physically measure fuel level. They are still the primary indication of fuel level in the airplane.

The GEM doesn’t measure level, but instead measures only fuel flow rate. The GEM totalizes the rate information to account for fuel used. If you know how much fuel you started with and how much you have used you can figure fuel remaining by simple subtraction.

The pilot must supply an accurate starting fuel level for this subtraction to produce the correct fuel remaining result. Should the pilot overstate the fuel quantity on board, the GEM will dangerously overstate the fuel remaining and the endurance time as well. The pilot must be careful and diligent when setting the fuel on board.

Getting the correct fuel total on board is in many cases pretty easy. If you fill up prior to takeoff the number is obviously the total available on board. If you partially fill a known configuration (say tips empty) then the total is easy to calculate. If you partially fill fuel tanks or add an accurately know quantity to a poorly known original value - errors will abound. Unaccounted fuel loss from leakage, fuel vent overflow or theft will of course produce erroneous results. So be careful and the GEM will deliver safe, reliable, and convenient fuel information. But be sure to cross reference the information on the primary fuel quantity gauges. Never trust a single source of fuel information when you have two on board. Fuel exhaustion still ranks highly among accident causes. Don’t let your engine stop until you’re parked.

G-SERIES GRAPHIC ENGINE MONITORS

INTRODUCTION

The G-series GEM's present a clear, concise, graphic picture of all engine temperatures simultaneously for interpretation at a glance. Never before has so much engine diagnostic information been available to the pilot and never before has the pilot been able to control mixture with such ease and precision for peak fuel efficiency.

Insight's G-series of Graphic Engine Monitors (GEM's) are available in a range of models from basic EGT/CHT monitor to full-featured with data-logging and advanced vibration analysis. All G-series GEM's have bright, full colour LCD displays presenting colour-coded bargraphs (white, green, yellow and red) and digital values for display of EGT, CHT and TIT. All other data shown in cyan on the GEM display are supplementary.

Insight's G-series GEM's also automatically record flight temperatures and will also interface with other data sources and report information to other instruments like MFD’s. The data-log files stored on the SD card can be easily retrieved by the pilot, in-flight or post-flight, for instant viewing or permanent record-keeping.

G-SERIES GEM MODELS AND AVAILABLE FEATURES

GEM Model Name	G4 Single	G4 Twin	G3	G2	G1
Bezel Size	3.125	3.125	2.25	2.25	2.25
EGT	X	X	X	X	X
CHT	X	X	X	X	X
TIT	X	X	X	X	X
PROBE DIAGNOSTIC	X	X	X	X	X
FUELFLOW	X	X	X	X	
OAT	X	X	X	X	
BUSS VOLTAGE	X	X	X	X	
DATALOGGING	X	X	X	X	
TACHOMETER	X	X	X		
MANIFOLD PRESSURE	X	X	X		
OIL TEMPERATURE	X	X	X		
OIL PRESSURE	X	X	X		
ACCELEROMETER	X	X	X		
CARBURETOR TEMPERATURE	X	X	X	X	X
INSTRUMENT VACUUM	X	X	X		
AUXILLIARY TEMPERATURE(S)	X	X	X		
RS-232 INTERFACE(S)	X	X	X		
VIBRATION	X	X	X		

A NEW APPROACH TO ENGINE MANAGEMENT

The GEM is a sophisticated tool for engine management. Its microprocessor performs many tasks that used to be handled by the pilot. One of the basic functions performed by the GEM is monitoring exhaust gas temperatures for all cylinders with one degree resolution. What is important is the exhaust gas temperature of a particular cylinder in relation to its peak. But peak EGT is not a constant; it changes with atmospheric conditions, altitude, power setting and engine condition and for this reason absolute exhaust gas temperatures in degrees Fahrenheit are quite meaningless.

The real objective of mixture management is finding a mixture setting that represents the correct position on the EGT/Fuel Flow Curve. As we will see later, this abstract task is easily accomplished by the GEM's microprocessor which samples EGT's for all cylinders many times a second and subjects this data to a complex mathematical analysis to identify peak. This capability allows the pilot to operate his or her aircraft engine at the most economical mixture settings.

It is generally known that EGT can be a valuable source of information for engine diagnosis and troubleshooting, but there is a great deal of confusion when it comes to interpreting this data. One of the basic principles of EGT engine analysis is that engine temperatures (EGT and CHT) achieve equilibrium in an engine operating at a constant power and mixture setting. What is often overlooked is that this equilibrium cannot be defined as a single point but rather a range of temperatures.

FUNDAMENTALS OF EGT

The basic ingredients of combustion are fuel, air (oxygen), compression, ignition, and timing. The measurement of Exhaust Gas Temperature (EGT) is really an indication of the harmony of interaction of these ingredients. A slight change in any of these five factors will result in noticeable changes in EGT.

The measurement and dynamic analysis of these changes is a very valuable tool for engine management. The use of exhaust gas temperature for mixture control depends on certain characteristics of combustion that are common to all engines. It is generally known that the exhaust gases get hotter as the mixture is leaned. This temperature rise is a sign of increased combustion efficiency as the optimum mixture setting is approached. If the leaning progresses past a certain point, the temperature will begin to drop. This temperature drop is the result of reduced energy output from the diminished fuel flow.

For a variety of reasons, the best operating mixture for aircraft engines is in the vicinity of this peak. Some high performance engines require slightly more fuel for cooling and run best on the rich side of peak while others are designed for operation on the lean side of peak. The shape and character of this curve is typical for all normally aspirated engines; it is, however, slightly affected by some turbocharger installations.

PRINCIPLES OF EGT MEASUREMENT

Exhaust Gas Temperature is measured with a temperature-sensing probe that penetrates the exhaust stack a few inches away from the cylinder. The sensing probe is made from a special alloy designed to provide long term protection for the temperature sensing elements inside. The temperature measurement is actually made with a thermocouple sensor. A thermocouple is a welded junction of two alloys that generates a tiny voltage when heated. The EGT probe uses Chromel (90% nickel, 10% chromium) and Alumel (95% nickel, 5% aluminum, silicon and manganese). Only 22 millionths of a volt are generated per degree Fahrenheit. The GEM measures these tiny signals and translates them into temperature. The EGT probes are designed to have a small thermal mass for fastest possible response, and the manufacturing procedures are tightly controlled to maintain probe calibration to within one degree.

In fact, the GEM will help you monitor mixture, timing, fuel distribution, compression, oil consumption, and many other subtle engine phenomena. The GEM can actually resolve engine phenomena that occur in millionths of a second.

PRINCIPLES OF CHT MEASUREMENT

Like EGT measurement, Cylinder Head Temperature (CHT) is monitored by means of a thermocouple, which generates a voltage proportional to its temperature. The GEM is designed to work with three different kinds of probes. The gasket probe replaces one of the spark plug gaskets on a cylinder and is held in contact with the cylinder by the spark plug. The spring-loaded probe screws into the temperature well in the cylinder and its tip is pressed against the cylinder by spring pressure. The third kind of CHT probe is called an adapter probe. It too screws into the temperature well, but unlike the spring-loaded type, it allows the factory installed bayonet probe to remain in place. While the basic principles of CHT measurement are similar to that of EGT measurement, the range of temperatures is much lower, typically 500° F or less.

THE GEM DISPLAY

The G-series GEMs offer a unique new function that facilitates setting mixture on either the rich or lean side of peak. In previous generation instruments the peak temperature was used behind the scenes to control flashing of a column to identify peak EGT, but it was never displayed to the user. The new GEMs not only continuously displays all instantaneous EGT values but goes one step further to display the current difference from peak (rich or lean) for each cylinder.

Once frowned upon, running lean-of-peak (LOP) EGT in cruise is now widely used to save fuel. Since leaning with reference to temperature was first used in the early 1950's, the temperature drop from peak has also been used to define a mixture setting. The term "75° rich" is universal and means 75 degrees lower than the peak temperature on the rich side. Leaning has always employed a relative number referenced to peak temperature. It is the only consistent metric available because the absolute temperature varies with altitude, power setting and outside air temperature.

Caution: Not all engine manufacturers recommend operation lean of peak EGT. Check your Flight Manual, Pilot's Operating Handbook, or the engine manufacturers operating instructions to determine if lean of peak EGT operation is allowed.

Legacy GEM instruments indicated peak EGT by the flashing of the bar-graph. The pilot would mentally note the bar position and move the mixture to drop a few bars to enrich the mixture. Now the pilot may reference the temperature difference display directly. The temperature difference information is calculated relative to peak EGT so it is only available for display during leaning after peak has been reached. After reaching peak a "leaning-box" appears on top of the EGT column containing the temperature difference from peak.

Most GEMs (not available on G1 model, see below) incorporate fuel flow analysis to also determine which side of peak the engine is operating on. It prefixes the temperature difference with an "R" for rich or "L" for lean. It further distinguishes Rich and Lean by colour. The box and number are displayed in white on the lean side and cyan on the rich side. The pilot may decide to operate at a certain temperature delta and tune the mixture until the desired number appears in the box.

To make it even easier to operate at a certain predefined temperature difference a user-settable threshold is provided. Reaching or exceeding this threshold is annunciated by the temperature box changing from hollow to solid filled. Precise leaning to a predetermined setting can be as simple as moving the mixture until all the boxes turn solid.

THE G1 DISPLAY

The G1 GEM offers the basic monitoring features for EGT/CHT/TIT and CT (Carburetor Temperature) as the other G-series GEMs but not the advanced leaning features (that require real-time fuel flow data). All EGT/CHT/TIT/CT data is continuously displayed in colour-coded bar-graph and numeric form, but neither mixture lean-of-peak (LOP) nor rich-of-peak (ROP) indication is provided. Leaning boxes do appear following peak-EGT events but the delta temperature number inside each leaning-box only shows the magnitude of temperature drop. The LOP or ROP mixture status must be determined by the pilot by knowledge of which direction the mixture control was moved following a peak-EGT event. Moving the mixture control to increase fuel flow after finding peak EGT will result in a ROP condition, and moving the mixture to reduce fuel flow after finding peak EGT will result in a LOP condition.

Users of the G1 GEM should disregard references to GEM fuel flow indications in this manual. Similarly any feature that requires use of the rotary control knobs or user configuration screens is not available on the G1 GEM and should be disregarded.

THE GEM ON START-UP

The GEM is ready to operate within moments of electrical power application. Within seconds after starting the engine, the white EGT bar graph columns will begin to appear on the GEM display. Each white column corresponds to the Exhaust Gas Temperature (EGT) of a cylinder. The columns are numbered with cylinder number. In some engines, the throttle will have to be opened to the fast idle range to get an EGT indication for all cylinders. As the cylinder heads begin to warm up, the display will indicate Cylinder Head Temperature (CHT) for all cylinders as a smaller green bar in each EGT column. Digital numbers below each bar graph column indicates the exact EGT and CHT for each cylinder. CHT is shown in green when within normal operating range, yellow when approaching the redline, and red when at or exceeding the redline limit. A red horizontal line across each column indicates the CHT limit.

Depending on the GEM model (see the models and features table) the top row of supplementary annunciations (in light blue) shows RPM or carburetor temperature, manifold pressure, fuel flow, buss voltage, oil pressure and OAT.

LEANING INDICATIONS

During leaning the EGT column rises pushing the peak indicator box above it. The peak indicator is just a box of column width that remains at the maximum temperature reached during leaning. Once the column drops below peak a new temperature difference numerical indication appears in the box showing the temperature difference of the current temperature below the peak. As each cylinder goes just past peak the fuel flow at peak is displayed in black in the top of the column. Ideally all cylinders will peak simultaneously but in practice they don't. The variation in the fuel flow numbers will identify how close they are. The peak indications may be reset (cleared) by pushing the bottom knob. Fuelflow data is not available on the G1 GEM.

SETTING THE THRESHOLD

The user may set the difference threshold anywhere from 0-99 by pushing the lower knob twice and then turning the knob to set the desired number. When complete a short push of the bottom button will clear the threshold setting message. Not available on the G1 GEM.

FIRST FLIGHT WITH THE GEM

During the first flight with the G-series GEM (excluding the G1) the pilot should enable EGT auto-ranging and set the inflection value to 800 on the user configuration screen. The instrument will calibrate itself for optimum bar-height. At the end of the flight the user should set EGT auto-range to 'SAVE' and set Save config to YES and push the lower button. This will save all configurable items in non-volatile memory and restore them to those saved values for each flight. Refer to the section on Setting Options for more detail on user configuration.

USING GEM ON THE GROUND

The temperature range of the GEM extends lower than most traditional EGT systems to include temperatures normally encountered at start-up. Under normal engine operation at 1,000 to 1,200 RPM, the GEM will produce a white bar EGT indication for each cylinder. The precise indication will vary from one installation to another, and it is not unusual to observe fairly large EGT differentials between cylinders at idle or taxi power settings.

One very useful feature of the GEM is its ability to detect abnormal combustion during the pre-take-off run-up. The primary purpose of the pre-take-off engine run-up is to verify the airworthiness of the engine's ignition system, plus carburetor heat and propeller control. Pilots without extensive engine instrumentation are accustomed to detecting engine and/ or ignition problems by an RPM drop or roughness during the run-up. With the GEM, a much more accurate diagnosis of problems is possible.

As you run your engine up to 1,700 or 1,800 RPM (or as recommended in your aircraft's Pilot's Operating Handbook), you will observe a rise in EGT for all cylinders, to about one third of full scale. Normally, these indications will vary somewhat from cylinder to cylinder. The GEM should be carefully observed during the magneto check. Combustion is initiated by two spark plugs firing simultaneously in each cylinder. Under single magneto operation, only one plug is firing, producing only one flame front in the combustion chamber, resulting in a slower, more prolonged combustion. This places the point of peak combustion pressure later in the power stroke and the tachometer will register a drop of 50 to 150 RPM. Since the exhaust gases have less time to cool before being expelled from the cylinder, the exhaust gas temperatures of all cylinders should rise. (50 to 100°F).

Various problems can be detected easily during run-up with the aid of the GEM. The absence of an RPM drop or EGT rise on single-magneto operation indicates trouble in the form of a hot magneto or defective ignition switch. A more common indication of trouble is the total disappearance of an EGT indication for one or more cylinders after switching to single-magneto operation, indicating a faulty ignition wire or spark plug. If the affected cylinder returns to a normal EGT indication when operating on the other magneto, you have isolated the problem to a single spark plug (or lead) in a single cylinder.

In the absence of adequate engine instrumentation, the initial diagnosis of fouled spark plugs is usually made on the basis of a greater RPM drop for one magneto than the other. Manufacturers' handbooks generally warn the pilot to regard any difference of more than 50 RPM between magnetos as suspicious. But it is important to note that an RPM drop will register only if more plugs are fouling on one magneto than on the other. If each magneto harness harbors one bad plug or lead this would cause a uniform mag drop and the double fault would go completely undetected. On the other hand, an entirely different malfunction such as a partially plugged injector could create the same symptoms. Careful analysis of GEM data can help a pilot determine the precise cause of mag drop, or pinpoint problems hidden behind a uniform mag drop. In both cases cited above, the G3 would indicate higher EGTs for the affected cylinders.

Run-up is also a good time to check carburetor heat (if present) and mixture control. Application of carburetor heat causes a reduction in the density (and therefore oxygen content by volume) of air coming into the engine, inducing an over-rich condition. This is indicated by a noticeable drop in engine RPM and exhaust gas temperature. If the application of the carburetor heat control fails to produce these effects, it is likely that the carb heat control is mis-rigged, causing the air box flapper valve to hang open and allowing hot air to leak into the carburetor on a full-time basis. This should be remedied as soon as possible.

During the mixture check, a uniform rise of EGT indications for all cylinders will confirm that the mixture control is functioning correctly. The amount of temperature rise will depend on the degree of mixture control movement. Each cylinder should show a rise in EGT upon leaning. Failure of a cylinder to show a significant rise, or an abnormally large EGT differential between cylinders in fuel-injected engines, may indicate a fuel injector nozzle constriction. In many engines, a large inter-cylinder EGT spread is normal at low power settings (even with fuel injection) so a diagnosis of this type is impractical until the pilot becomes thoroughly familiar with the normal indications for his or her engine. Even so, this type of diagnosis, easily made with the G-series GEMs, is virtually impossible with other EGT systems.

USING THE GEM ON TAKEOFF

The GEM can be used during takeoff to identify a very serious class of combustion problems that can result from poor fuel distribution at take-off power settings.

The combustion phenomenon known as pre-ignition can do extensive damage in a matter of a few seconds if left unattended. This combustion process produces abnormally high temperatures in the combustion chamber which results in immediate full-scale EGT indications followed by a rise in cylinder head temperatures. Should this type of indication occur during the takeoff roll, the takeoff should be aborted. If takeoff has proceeded beyond the point of no return, power should be reduced immediately (maintaining flight) and the mixture enriched if possible to make the temperature drop in the affected cylinder(s). A precautionary landing should be made as soon feasible. Pre-ignition can be caused by red-hot cylinder deposits or overheated exhaust valves. Regardless of cause, pre-ignition, once started, causes an extreme temperature rise in the combustion chamber and is self-sustaining until engine failure occurs (often in a few seconds). Broken connecting rods, melted pistons, and cylinder head separation are among the common pre-ignition induced failures. A second type of pre-ignition that does not fit the previous definition is magneto induced pre-ignition. It results from extreme timing errors in magneto adjustment or failure of the magneto itself.

Detonation in automobiles is commonly referred to as *ping* or *knock.* It is an unusually rapid form of combustion that follows ignition induced combustion and is caused by high compression, high temperatures and a lean mixture. The rapid combustion of detonation is significantly advanced by the time the exhaust valve opens and the temperature encountered by the EGT probe is lower than normal. Detonation results in higher peak combustion temperatures and pressures which translate into *higher* CHT's and *lower* EGT's. More importantly, detonation imposes significantly greater stress on the engine components than normal operation. It may be caused by excessively lean operation at high power settings because of fuel system malfunctions, injector nozzle constrictions, improper mixture control settings, insufficient fuel octane or avgas contaminated by jet fuel.

LEANING FOR TAKEOFF

Leaning normally aspirated engines for takeoff is advisable for best performance under high density altitude conditions and this is something that can be done with confidence and accuracy with the GEM. Remember that the full-throttle, full rich-mixture setting is designed to provide an enriched fuel flow for proper engine cooling during takeoff at sea level on a standard day. This over-richness is a FAA-mandated minimum of 12% above the worst case detonation-onset fuel flow.

With increasing density altitude, this over-richness robs your engine of power. Leaning on a high altitude takeoff can restore a significant amount of power and add measurably to aircraft performance. Consult the *Pilot's Operating Handbook* for the airplane manufacturer's recommended high altitude takeoff procedures. On some aircraft equipped with fuel flow gauges, the full-power altitude reference marks indicate acceptable fuel flows for various altitudes (typical reference marks are S.L., 3000, 5000, and 7000). Sometimes a specific temperature (e.g. 150°F rich of peak EGT) is specified as the takeoff power mixture guideline.

After some experience with the GEM to determine the location of peak EGT, the GEM can be used to set the mixture using this guideline, or (with careful operator technique) to produce the EGT indications similar to a normal sea level takeoff.

LEANING NORMALLY ASPIRATED ENGINES IN CLIMB

Most normally aspirated aircraft benefit from mixture leaning during climb with less plug fouling, better engine performance, smoother operation and increased economy. The full throttle, full rich mixture setting is designed to provide an enriched fuel flow for proper engine cooling during takeoff at sea level on a standard day. As the aircraft climbs, the air density decreases causing an effective enrichment of the mixture, eventually robbing the engine of power. Leaning in climb is advisable for best performance and will result in a cleaner engine and easier cruise leaning later on.

After safely clearing the field, observe the location of the tops of the bars on the GEM. As you ascend, the effective mixture enrichment that results from the decreasing air density causes the EGT reading to fall. Observe one column as a reference. When the reading drops, lean the mixture until the reading goes up, restoring the bar. Repeat this procedure each time the EGT reading drops due to ascent into less dense air to ensure that highest EGT. Aircraft equipped with fuel flow gauges may have altitude reference marks to guide leaning during climb.

This procedure for leaning in climb does not apply to turbocharged engines which do not experience the same air density variations due to altitude.

LEANING THE ENGINE IN CRUISE WITHOUT LEAN MODE

There are occasions when the pilot may wish to lean manually. It is informative on the first GEM training flight to lean the engine without Lean Mode to get a feel for the instrument. As you lean, the bars will rise, reach a maximum, and then fall at the onset of engine roughness. If you lean too far the engine will stop. Short flights in high traffic density airspace demand maximum pilot attention to traffic avoidance. When busy, the pilot may lean quickly by watching the bars rise and stopping when they are still below the normal average indication. This procedure will be within a gallon or two per hour of the optimum mixture setting, and can be used as a temporary measure until time permits using the complete leaning procedure described below.

THE BASIC GEM LEANING PROCEDURE IS AS FOLLOWS:

Establish cruise altitude and cruise power. Make initial trim adjustments, etc. as needed to establish cruise.

Perform a coarse leaning or preliminary leaning of the engine until the fuel flow is a couple of Gal/hr more than the normal cruise indication. Pause for two minutes to allow the engine to stabilize and cylinder head temperature to return to normal. It is advisable to allow up to five minutes for the turbocharger (if so equipped) to stabilize in output before attempting final leaning. During this time you can make final trim adjustments to the airplane, reset cowl flaps, etc.

Set the lean threshold as described above. Now slowly lean the mixture until one of the EGT lean boxes appears at the top of the EGT bars. This final leaning should take about five seconds. The first lean box to appear on top of the EGT bars column of bars identifies the leanest cylinder (the first to reach peak EGT). Continue leaning until the lean boxes appear on all cylinders. To operate rich of peak, move the mixture control in the rich direction until the boxes show solid cyan with an ‘R’ number inside in black. To operate lean of peak, move the mixture control in the lean direction until the boxes show solid white with an ‘L’ number inside in black. ("L" and "R" not available on G1 GEM)

Note: Engine manufacturers differ in their approval of operation at peak. At the time of publication Lycoming recommends operation at peak for power settings of 75% and less while Continental recommends operation at peak for power settings of 65% and less.

Do not lean to peak EGT power settings greater than those recommended by the manufacturer.

This procedure may not be applicable to all engines. In some aircraft the mixture may be dictated by other parameters:

LEANING IN CRUISE

The GEM is ready for leaning at any time however the GEM assumes that all cylinders are starting on the rich side of peak. The bottom control knob may be pressed to clear any lean boxes that may be on the GEM screen. As the pilot leans the mixture the bars will rise then fall leaving a peak temperature box behind. This box will show the difference in degrees from peak and whether the mixture is rich or lean of peak. Temperatures preceded by an ‘L’ e.g. ‘L47’ are lean of peak while those prefixed with an ‘R’ are rich. In addition to the L or R letter, LOP setting are displayed in white and ROP in cyan. (G1 GEM only shows the temperature difference, no "R" or "L" available)

The pilot may set a threshold which is used to trigger the box from being hollow to being solid filled. Should the user wish to operate say 25 degrees lean he/she may set the threshold and lean until all the lean boxes are displayed as filled. This is a simple and easy way to lean correctly and precisely.

RESTARTING THE LEANING PROCESS

The pilot may restart the leaning process at any time. First enrichen the mixture to the rich side of peak, press and hold the bottom control knob for a few seconds to clear the lean boxes, and then lean the mixture.

LEANING BY TURBINE INLET TEMPERATURE

Some turbocharged engines are designed to be leaned by reference to Turbine Inlet Temperature (TIT). This may imply that the TIT is the first temperature to reach redline and is the overall limiting factor in the leaning procedure. Some manufacturers may put a limit on the TIT to increase detonation margins. In general, turbochargers are very much alike and most manufacturers specify a redline of 1650° F. Some operate as high 1750° F. Because indicated temperature is largely dependent on probe placement and exhaust flow, it may not be the same as that experienced by the turbo. Aircraft manufacturers have very likely taken this into account when deciding on the official TIT redline.

LEANING RESTRICTIONS

Some aircraft have restrictions on leaning that must be observed. The recommendations of this manual are not intended to supersede any specific requirements for engine operation as stated by the aircraft or engine manufacturer. The pilot should consult the Pilot's Operating Handbook and follow the manufacturer's recommendations. These restrictions typically, (but not exclusively) apply to aircraft with marginal cooling airflow at high altitude or high angles of attack or turbocharged engines where concern over turbine inlet temperature, compressor discharge temperature, detonation margin, or cylinder head temperature must dictate mixture settings.

There are certain times when you should not lean to peak or even attempt to find peak. In full power climb or any time the engine is operating at power settings in excess of 75%, leaning to peak could result in detonation and serious engine damage. This is especially true for high performance engines and turbocharged aircraft.

THE IMPORTANCE OF MEASURING TURBINE INLET TEMPERATURE

A single probe mounted in the exhaust inlet to the turbocharger measures turbine inlet temperature. The TIT display shows the temperature of the exhaust gases that drive the turbo. In many cases this probe is just a foot or so downstream of all the EGT probes. At first glance this measurement appears redundant. Why read the temperature again when it is just the collection of all the EGTs? TIT is not a simple function of the collective exhaust gas temperatures. It may be hotter than the hottest EGT that feeds it or cooler than the coolest EGT. The temperature measured by the EGT probe is the average of the pulse of high temperature gases that exit the cylinder when the exhaust valve opens. The TIT probe sees the collection of pulses from all cylinders that feed it and will indicate a higher temperature.

Turbo action is throttled by the waste gate valve that forces a portion of the exhaust gases to bypass the turbo. At low altitude, with little demand for turbo-charging, the waste gate will direct a large part of the exhaust past the turbo and the TIT probe will read a lower temperature. At higher altitudes the waste gate will close to direct more energy to the turbo and a higher TIT will be indicated.
TIT is not just a simple function of EGT and this is very important to consider when operating a turbocharged engine. A power setting and fuel flow that may be well below peak EGT and well below the TIT redline temperature at 9000 ft may easily exceed the TIT redline at 16000 ft. The higher temperature results from more exhaust gas driving the turbo to restore the manifold pressure at the

higher altitude.

The TIT reading is a key factor in leaning the turbocharged engine. It also provides diagnostic information that is unavailable from other sources. A waste gate system malfunction will affect TIT readings under conditions where other indications are normal. Should the waste gate stick closed at high altitude, all indications would appear normal. Subsequent throttle power reductions for descent would show a deceptively normal decrease in manifold pressure but abnormally high TIT readings for that situation. Other factors such as ignition, fuel distribution, induction, or compression that affect EGT will also affect TIT; sometimes with detrimental results. For example, ignition failures that cause the EGT to rise may increase the TIT past redline.

SPECIAL CONSIDERATIONS FOR TURBO-CHARGED ENGINES

Turbocharged engines exhibit some special characteristics that result from the interaction of the turbocharger, throttle, waste gate controller, and other engine components. These interactions will vary in degree depending on the engine type and installation. In the normally aspirated engine, the components of combustion are essentially fixed for a given throttle and mixture setting. Any mixture control change results in a direct mixture change. The turbo has one additional complication that results from mixture changes. A change in mixture changes the exhaust gas energy that drives the turbo. This change in turbo drive energy changes the induction or manifold pressure and temperature and may or may not be compensated for by the turbo waste gate controller.

The turbo also has significant inertia, which causes a lag in response to changes in drive energy. The result of this turbo bootstrapping is a change in the EGT/Fuel Flow Curve depending on the direction of mixture movement. This lag must be understood and taken into consideration to properly lean the engine. This change in the curve becomes evident if the pilot tries to enrich the mixture to drop the temperature one bar. In most turbocharged engines it will take considerably more fuel flow to drop the temperature one bar than it did to achieve that temperature on the way up. For example, in a normally aspirated engine, enriching for a 25 degree drop may take a 1/2 gph increase in fuel flow. The same model engine when turbocharged may require a 2-4 GPH increase in fuel flow to get the same 25 degree drop. Paradoxically, the pilot may even see EGT rise when he starts enriching before it begins to fall.

Another observable characteristic is that the required fuel flow is dependent on altitude under conditions of constant RPM and manifold pressure. It may seem reasonable that the optimum mixture for a given power setting should remain constant. However, when the turbo compresses the induction air it also increases its temperature and reduces its density. Although the manifold pressure is restored, the oxygen content of the induction air is reduced because it is a function of air density. It should be remembered that the exact nature of this complex and confusing issue is dependent on the engine and installation. For this reason it is difficult to make generalizations about the leaning characteristics of turbocharged engines, but one thing can be said with certainty: ***a generous enrichment of the mixture from peak will prolong the life of exhaust valves, the waste gate and the turbocharger itself.***

SPECIAL CONSIDERATIONS FOR TWIN ENGINE AIRCRAFT

Some twin engine aircraft exhibit an unusual mixture control reversal characteristic. We speculatively attribute this to the long flexible cable used to link the cockpit controls with the engine. The phenomenon is easily observed in aircraft with fuel flow gauges. When the pilot pulls back on the mixture controls to lean the engines, fuel flow is reduced and the EGT rises as expected. But when the mixture controls are pushed forward to enrich the mixture, the fuel flow continues to drop and the EGT drops on the lean side of peak. Even though the mixture control is moved in the rich direction, leaning continues. It would appear that the function of the mixture control has temporarily reversed! Continued movement of the mixture control picks up the slack and normal mixture function resumes. The magnitude of this phenomenon varies from aircraft to aircraft, but we have observed transitions of up to 1.5 GPH past peak before the fuel flow began to increase. Monitor the fuel flow to identify this phenomenon with your GEM.

GEM DISPLAY PAGES

The G-series GEM models have either two push-button switches (G1) or two control knobs that operate combination rotary and push button switches (G2,G3,G4). The top knob in general controls screen selection while the bottom knob controls items within the given screen. Each screen assigns its own functional needs to the controls that may change depending on context. A screen may also label the controls with guidance information like “Push to exit”.

Some of the many revolutionary new features of the GEM system include:

Engine vibration measurement and analysis.
Specialized analysis for propeller balance, turbulence and even landing shock
Integrates, logs data from G3, TAS Air Data and GPS for the complete picture
SD Card stores all engine, air, winds aloft and fuel data
Entire aircraft life history directly on SD card in PC compatible form
Specific functionality for safe Lean of Peak operation
Oil Temperature and Pressure
Manifold Pressure, Fuel Flow and RPM
OAT
Carburetor Temperature
Buss Voltage

THE STARTUP SCREEN

On power-up the G-series GEM will briefly display a status screen indicating instrument Serial Number, Real-Time Calendar Date and Time, Software Revision, Hardware Revision and Security Code. Push and hold one of the control knobs to pause the screen. Release the knob to resume normal operation.

GEM PAGES

The Bar-Graph Display Page (The "GEM" Screen)

Each Cylinder's Exhaust Gas Temperature is displayed in white bar graph form and is interpreted much like a conventional mercury thermometer. The higher the bar, the higher the temperature. The cylinder head temperature is displayed in green single bar format. During normal operation it shows as a green illuminated bar in the lower half of the bar column. Since EGT is normally higher than CHT, the green bar which represents CHT is on top of the white illuminated EGT bar and stands out clearly. However, when the engine is shutdown, the EGT quickly drops to zero and the cylinders remain warm for sometime. The GEM provides a reliable indication of cylinder head temperature even with the engine shut down. Should an EGT probe fail, the entire EGT column for that cylinder will go blank, and the numeric indication will show dashes (" ---"), but the CHT bar will still remain green. The failure of any one probe will not affect the operation and display of any other probe.

PROBE DIAGNOSTIC PAGE (ALL G-SERIES GEMS)

Troubleshooting avionics is an expensive and time-consuming process. Often times the procedure requires access to the instrument connector for continuity measurements. This might take hours of instrument panel disassembly just to touch the connector. We needed something better, easier to use, less time consuming and therefore less expensive. The Probe Diagnostic feature is the solution.

The G-series GEM measures the resistance of the thermocouple temperature probe junctions and each of its two lead wires. Each probe is indicated on the diagnostic screen by a pair of numbers showing the resistance measurement (in Ohms) of each wire of the pair. Typical values range from zero to 10 Ohms for short wiring harnesses, and up to 30 Ohms for longer wires in twin-engine aircraft. Note the values for reference in the future to detect any changes. Colour coding of the indications are controlled by adjustable Maximum and maximum-difference threshold values. The thresholds are factory-set to typical practical values but may be adjusted to closely match the probes and wiring in a given installation. This will alert if any wires are broken, chafing, or shorting and whether the probe is degrading or near end-of-life. You can replace probes at your convenience instead of waiting for a probe failure. This will totally eliminate the possibility of intermittent behavior caused by probe problems. The GEM also automatically diagnoses all the thermocouples at power-up and records the resistance measurements in the data-log.

PERIODIC TEMPERATURE VARIATION PAGE (G3 AND G4)

This is a new form of engine analysis. Some valve related engine faults produce a slow periodic variation in EGT. The oscillation rate is on the order of one cycle every minute or two. This is just too slow to be identified by casual observation of the temperatures alone. Yet it is very important to discover this phenomenon because it may lead to a catastrophic engine failure. It readily appears in a slow sampled spectrum analysis. A normal indication in cruise flight will be a flat line with a little noise, while a trouble indication will show as an obvious spectral peak.

VIBRATION SPECTRUM (G3 and G4)
Power plant Vibration Page

The Insight vibration sensor is available as a stand-alone unit or collocated within the Insight fuel transducer. Engine vibration is sensed by a 3-axis accelerometer (X=longitudinal, Y=lateral, and Z=vertical). A valid RPM signal is required to phase lock the vibration sample rate to the speed of the engine. Vibration data is automatically transferred from the sensor to the GEM display by a high-speed serial-communications link.

Inside the GEM a Fast Fourier Transform (FFT) converts vibration samples to a frequency spectrum for each of the X, Y, and Z axis. Each axis can be viewed either in instantaneous form (X1, Y1, Z1) or averaged form (AX1, AY1, and AZ1). The instantaneous screens update about once per second showing each new FFT result as they are calculated. This provides a complex and constantly changing display that reflects the highly dynamic nature of the engine's accelerations. Combining the results of many FFT conversions produces the more intuitive graphs shown on the averaged screens.

The vibration data is plotted on the GEM Vibration Spectrum screen as a line-graph with vibration amplitude referenced to a logarithmic scale (db) on the left side of the screen, versus harmonics (multiples) of the engine speed at the bottom of the screen ("1" = crankshaft speed). The logarithmic scale allows an enormous range of vibration amplitudes to be displayed on a small screen (about 4000:1). The measurement systems noise floor may be approximately 20 db near the fundamental (crankshaft speed) and less at higher harmonics. The engines vibration signature appears as peaks rising above the noise floor. The GEM will automatically adjust the displayed amplitude to optimize readability.

Step through the various axis screens by momentarily pushing the top control knob. The multiple axes facilitate identification of various vibration sources. Pan & zoom the vibration display to focus on any area of the display by pushing and turning the bottom control knob (ex. AX1, AX2, etc.).

Vibration data is not automatically saved in the data log but a vibration spectrum snapshot (X,Y, and Z) can be added to the log by pushing and holding the top control knob for a few seconds.

PROP BALANCE
Propeller Balance Page (G3 and G4)

Propeller balance has a significant effect on engine smoothness. Just the slightest propeller imbalance has a profound affect on passenger comfort.

Typically props are balanced on the ground using helicopter balance equipment. The GEM uses the engine vibration accelerometer and the once per rev or once per 2-rev spark signal to derive prop balance values. Because the sample interval is phase locked to the prop rotation the FFT magnitude and phase of the fundamental harmonic is a good measure of prop balance. Not all of the fundamental harmonic vibration is attributable to the propeller but adjusting balance to minimize it, no matter what the cause, achieves the most comfortable result. The harmonic magnitude is a measure of the correction weight required and the harmonic phase indicates the clock angle of the correction weight location. The balance display shows phase as a polar vector like the hand of a clock and magnitude as a linear bar graph with a numeric reading.

Once a calibration value has been determined a second bar graph with numerical presentation displays the mass of the required correction weight directly.

A change in prop balance may indicate a propeller fault, blade damage, and spinner damage, ice in the spinner, blade ice accumulation or ice shedding.

TAKE-OFF G-FORCE PAGE (G3 and G4)

The GEM's internal accelerometer continuously measures G-loading along the longitudinal axis of the aircraft. Instantaneous G-force is plotted on a continuously scrolling line-graph showing the current force and the last several seconds of flight. Normal flight maneuvers may impose small accelerations along this axis but Take-off and Braking forces are clearly noticeable on this page. The G-force is also stored in the data log for post-flight analysis.

TWO AXIS TURBULANCE PAGE (G3 and G4)

The GEM's accelerometer also measures turbulence, landing shock and yaw. Knowledge of G forces will help the pilot to operate the airplane safely by slowing to maneuvering speed. Landing shock is a good training aid for smooth landings and a predictor of structural damage. Data logged G force will report unauthorized aerobatic activity or abuse of rental aircraft. It could also be useful in accident investigation.

Configuration Pages

There are six configuration pages for the G2, G3, and G4 GEMs . The User Config Page is the only one accessible by the pilot in flight. The Set Time/Date, registration screen and other screens are accessible to configure the instrument at installation time. There are no field-accessible configuration pages on the G1 GEM.

GENERAL INFO
REGISTRATION
ENGINE CONFIGURATION
CLOCK / CALENDER
USER CONFIGURATION
FF K-Factor

Data-Logging

Files are created directly in CSV format (comma separated values) for direct importation in Excel Logging of engine temperature data on a routine basis allows the creation of a complete engine-operation history, a detailed record documenting each hour of an engine's life.

Data-logging with the GEM provides the benefits of long-term trend monitoring through a standardized personal computer interface. The GEM data-log system makes it easy to retrieve log data from all flights.

The GEM automatically records parameters during every flight. Each flight's data is stored in an individual log file on the SD Card. Every file has an identification header containing the date, time, aircraft- registration and data log configuration. All data is sampled and recorded at one second interval of flight with essentially no limit as to size. Data acquired with the GEM can be viewed directly in raw form, or imported into spreadsheet and database programs for graphical analysis.