ENGINE MONITORS for GENERAL AVIATION PISTON ENGINES CONDITION MONITORING

Dubravko **MILJKOVIĆ**, HEP, Zagreb, CROATIA, Phone: (1)6113032; dmiljkovic@hep.hr

ABSTRACT – *Classical engine gauges give very basic information about engine operation and condition. With graphical engine monitors is now possible to have substantially more diagnostic information available in a timely and usable manner. This information may provide better and more efficient engine operation. It can also detect most impeding engine problems.*

Keywords: *engine monitor, aircraft, piston engine, general aviation*

1. INTRODUCTION

Vast majority of general aviation aircrafts (popularly known as small private airplanes) are powered by gasoline piston engines. The main source of engine information available to pilot are several gauges indicating cylinder head temperature (CHT), exhaust gas temperature (EGT), engine rotational speed (RPM, tachometer), fuel flow, oil temperature and oil pressure, ***Figure 1***. These gauges give very basic information about engine condition. E.g., single CHT and EGT gauge gives an average of each cylinder's head and exhaust gas temperature. Engine monitor, [1], [2], replaces this older method of viewing of only one temperature at time with precise multi- cylinder engine monitoring of EGT and CHT

Figure 1 *Classical gauges for monitoring of aircraft piston engine (CHT, EGT, RPM - rotation speed, FF - fuel flow, oil temperature and oil pressure)*

temperature plus myriad of other more or less important parameters. Such engine monitors cover much more engine data then basic gauges in a cockpit (about dozen of parameters that are also recorded and can be analyzed later). By monitoring engine parameters it is possible to detect minor engine problems before they become large ones. This device augments diagnostic possibilities of classical boroscope inspection, engine oil analysis and magnetic chip detector (detection of metal particle – engine debris).

2. AIRCRAFT PISTON ENGINE

Piston engine is a heat engine designed to convert energy into rotational mechanical motion. It uses reciprocating pistons to convert pressure into a rotating motion. Typical main four strokes of the petrol internal combustion engine are intake, compression, power and exhaust strokes, as shown in ***Figure 2***. Piston aircraft engine is not very efficient at converting energy contained in a fuel to a mechanical energy, ***Figure 3***.

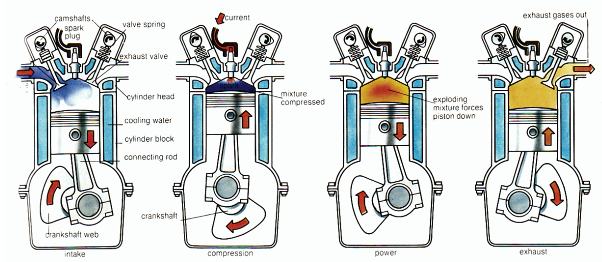

Figure 2 *Four strokes of the petrol engine*

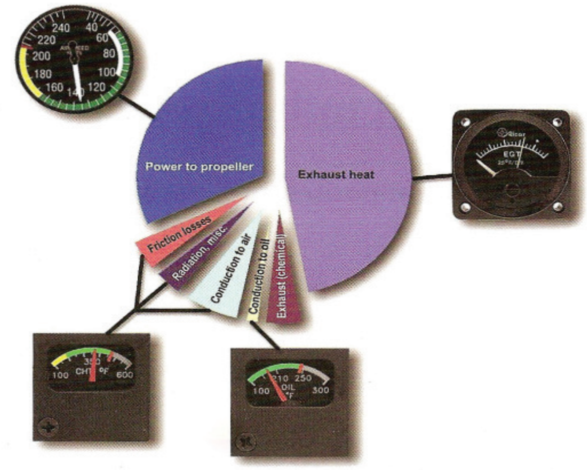

Figure 3 *Distribution of energy contained in fuel in a piston engine, adopted from [3]*

Only about one-third of the energy contained in Avgas is converted into useful energy to the propeller, [3]. Roughly half the fuel's energy is wasted out the exhaust pipe (if no turbocharger is provided). The remaining one-sixth is transferred to the cooling air passing over the cylinder fins and through the oil cooler.

Quality of the combustion process can be assessed by monitoring the temperatures of exhaust gases. Diminished efficiency of the combustion process indicates various engine problems like low compression, non-uniform fuel distribution, faulty ignition, and clogged injectors, [4].

An aircraft engine, as one shown in ***Figure 4***, does not have a detonation detector, oxygen sensor or a computer to control timing or fuel/air mixture based on throttle position, temperatures, detectors or sensor inputs (FADEC equipped aircraft piston engines are still very rare). If a pilot chooses, an aircraft

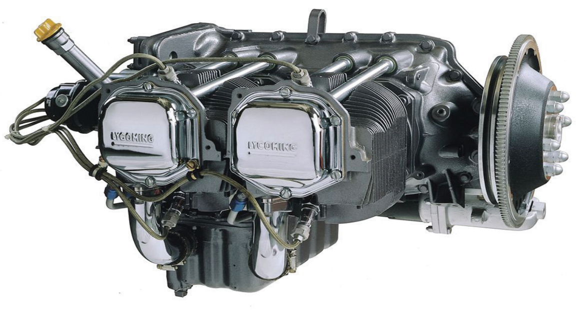

Figure 4 *Lycoming IO-320 (four cylinder fuel injection engine commonly used on Cessna 172 aircraft)*

engine can be run at temperatures that will significantly reduce the life of some of its parts and there is no automatic system or computer to prevent or limit engine damage, [5]. Excessive EGTs and/or CHTs cause engine damage on a regular basis.

2. GRAPHICAL ENGINE MONITOR

Engine monitor is advanced and accurate piston engine-monitoring instrument that improves the pilots understanding of engine operation, [1-5]. Temperatures are shown graphically as bars on the display of an engine monitor, ***Figure 5***. Each column in the bar on a display is composed of a stack of segments. The total height of each column represents the EGT while the missing segment in the column represents the CHT. In addition to graphically displaying EGT and CHT temperatures, the instrument continuously displays Turbine Inlet Temperature (TIT) on turbocharged engines.

Figure 5 *Engine monitor with bar graph display (Insight Avionics, older GEM 603)*

For twin engine aircraft special variants of engine monitors are developed that simultaneously monitor and show parameters of both engines on a display of a single instrument, [6], ***Figure 6***. New products often have color display with separate columns for EGT and CHT, [7], ***Figure 7***. Monitored engine

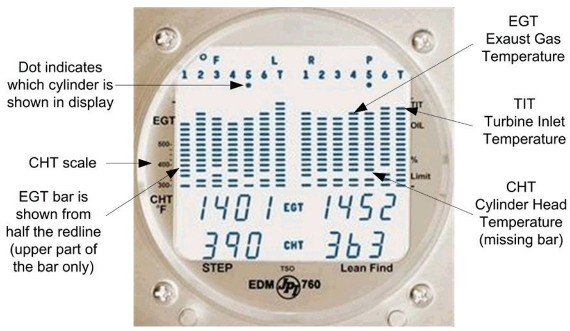

Figure 6 *Engine monitor with bar graph display for twin engine aircraft (JPI EDM 760)*

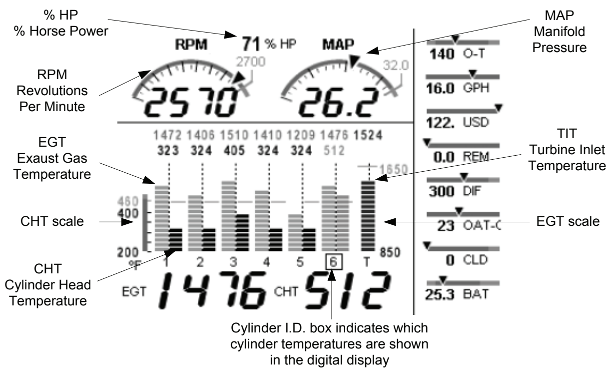

Figure 7 *Engine monitor with separate bars for EGT and CHT (JPI EDM 830)*

parameters (available in JPI EDM 830) are shown in ***Table 1***. Similar parameters are also available in other modern engine monitors

Table 1 *Monitored engine parameters (JPI EDM 830)*

Parameter	*Description*
EGT	Exhaust Gas Temperature
CHT	Cylinder Head temperature
OIL TEMP	Oil Temperature [1]
OIL PRES	Oil Pressure [1]
TIT 1	Turbine Inlet Temperature 1[1]
TIT 2	Turbine Inlet Temperature 2 [1]
OAT	Outside Air Temperature
CDT	Compressor Discharge Temperature [1]
IAT	Intercooler Air Temperature [1]
CRB	Carburetor Air Temperature [1]
CDT - IAT	Intercooler cooling
RPM	Rotations Per Minute
MAP	Manifold Pressure
% HP	% Horse Power
CLD	CHT Cooling Rate [2]
DIF	EGT Span [3]
FF	Fuel Flow [1]

[1]optional, [2]fastest cooling cylinder, [3]difference between the hottest and coolest *EGT*

Separate temperature probes are implemented for each cylinder. Cylinder Head Temperature probe is fitted to the cylinder head's thermowell. Exhaust Gas Temperature is measured with a probe that penetrates the exhaust stack a few inches from the cylinder. Turbine inlet temperature is measured by a probe mounted in the exhaust inlet leading to the turbocharger. It must be measured separately as it is not simple function of separate EGTs. Temperature probes are illustrated in ***Figures 8-10,*** and its mounting in ***Figure 11***.

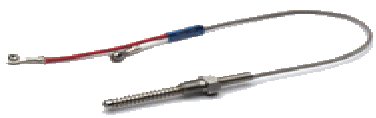

Figure 8 *CHT Probe*

Figure 9 *EGT Probe*

Figure 10 *TIT Probe*

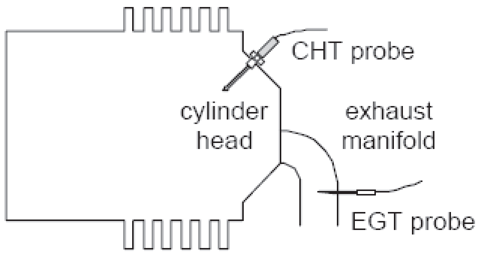

Figure 11 *Mounting of temperature probes, adopted from [4]*

3. *OPERATING MODES*

Engine monitor typically has monitoring and lean operation mode.

3.1. MONITORING MODE

In monitoring mode there is percentage view and normalized view, [1, 4-8]. Percentage view easily discerns EGT differences across all cylinders. In normalized view EGT temperatures are displayed with all column peaks initially set to the same half-height. This is useful for trend analysis as it is possible to compare current engine operation to prior engine operation.

3.2. LEAN OPERATION MODE

Leaning is a process of adjusting fuel/air ratio, [1], [2]. Adjusting the mixture is necessary

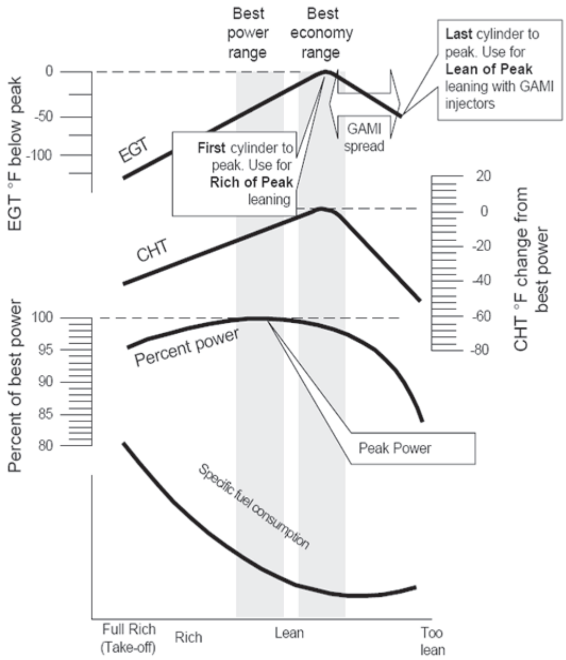

Figure 12 Various relationships between the mixture, fuel flow and engine power, adopted from [4]

because during the flight engine operates at various altitudes and corresponding air pressures. It restores a significant amount of engine power and hence improves aircraft performance. Leaning process can be performed by monitoring EGT temperature. As the mixture is leaned, EGT rises to a peak temperature and then drops as the mixture is further leaned, [1, 4-8], ***Figure 12***. The best operating mixture for aircraft engines is in the vicinity of this peak (lean of peak or rich of peak). Engine monitors are equipped with the leaning find mode that helps identify the first cylinder (in case rich of peak) or last cylinder (if case lean of peak) to reach peak EGT during a leaning process. When this mode finds the leanest cylinder it is not necessarily the hottest cylinder, but the cylinder that has peaked, [4], [6], [7].

4. COMON FAULTS DIAGNOSTICS

Engine monitor is useful during all flight phases. Its benefits are apparent to pilots even while aircraft is still on a ground (during taxi, run up and take off). Benefits include combustion diagnosis and monitoring of all critical temperatures. Data shown on a display help diagnose mixture, timing, compression, oil consumption and other engine phenomena that can be used for early detection of engine problems.

Documentation accompanying engine monitors, [1, 4, 6-8], gives advices what to verify (e.g. uniform rise in EGT with application of mixture) and what to be alert for (e.g. high or uneven EGT or CHT, cooling rate CLD) for various flight phases of operation: Taxi Run up Take off, Climb and Full Throttle Operation, Cruise (leaning) and Descent.

In all flight phases pilot must strictly observe the red-line temperature limits imposed for CHT, EGT and TIT during takeoff, climb and high-performance cruise power operation, [9]. Engine monitors have custom predefined (but also custom adjustable) alarm limits set to encompass all flight regimes, ***Table 2***. Values for alarm limits are determined from engine producer documentation. Default alarm limits are set to encompass all flight regimes. When a parameter falls outside of its normal limits, the digital display will flash with the value and abbreviation of the alarming item.

4.1. SHOCK COOLING

Shock cooling is an excessively rapid decrease in temperature of cylinders that may happen during descent with idle engine power setting. Damage from shock cooling often manifests itself as stuck valves and cracked cylinders. By observing CLD parameter it is possible to operate an engine in a fashion that avoids rapid cooling of cylinder and associated damage.

Table 2 Default Engine Monitor Alarm Limits

Measurement	*Default Low Limit*	*Default High Limit*
CHT		450 °F 230 °C
OIL	90 °F 32 °C	230 °F 110 °C
TIT		1650 °F 00 °C
CLD		-60 °F/min -33 °C/min
DIF		500 °F 280 °C
MAP		32 inch Hg

4.2. DIAGNOSTIC FAULT PATTERNS

Engine diagnostic charts in accompanying documentation contain examples of various bar patterns shown on a display and corresponding symptom, probable cause and recommended action that can help diagnose and solve engine problems. Patterns shown in ***Figures 13*** and ***14*** illustrate just two engine problems. There are about 15 bar graph patterns in diagnostic charts, [1, 4, 6-8].

- Decrease in EGT of one cylinder may be caused by intake valve not opening fully or faulty valve lifter

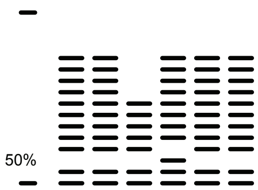

Figure 13 *Intake valve or valve filter*

- EGT and CHT are not uniform in case of dirty fuel injectors or fouled plugs

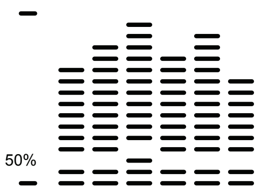

Figure 14 *Dirty fuel injectors or fouled plugs*

4.3. DATA LOGGING

Engine monitor automatically records engine parameters during each flight. Example of one part of engine log (raw data) is shown in ***Figure 15***. Recorded data can be downloaded with cable, wireless connection or memory card for later analysis using software, [10], installed on a PC for sophisticated graphical analysis as illustrated in ***Figure 16***. This also includes plotting the trends of user selected measurements and generating flight summary. Analysis software may also include engine monitor simulator that simulates operation of engine monitor display based on engine data logged in previous flights. Suspicious data logs can be sent to a mechanic or engine manufacturer for further clarification.

5. CONCLUSION

The graphic engine monitor is the essential tool for modern engine management. It improves the pilot's understanding of engine operation and removes guesswork from engine management.

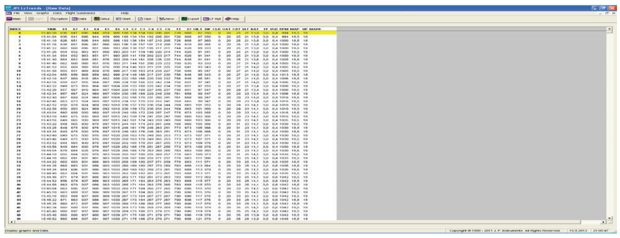

Figure 15 *Example from engine monitor log*

Figure 16 *Graphical representation of engine parameters during one flight. Upper curves show main data (EGT, CHT, TIT), lower curves show optional data (CLD, OILT, FF, RPM, MAP)*

Simultaneously it increases reliability of piston engine, flight safety and operational economics. With its diagnostic capabilities many impeding failures can be detected. Engine leaning with built in leaning find function is crucial for optimum performance with benefits in improved fuel economy, reduced maintenance costs, and extended engine life.

6.REFERENCES

1. Graphic Engine Monitor Data Logging System, Insight Avionics, USA, 1995 **| 2.** Bush M., EGT Myths Debunked, Cirrus Pilot, Vol. 5, No. 7, July/August 2010 **| 3.** Bush M., Understanding CHT and EGT, Cessna Pilots Association, April 2009 **| 4.** Pilot's Guide: Engine Data Management, EDM-700, EDM-800, EDM-711 Primary, J. P. Instruments, California, USA, 2007 **| 5.** Roberts R., The Pilot's Manual for Leaning and Diagnosing Engine Problems, Electronic International, Oregon, USA, 2004 **| 6.** Pilot's Guide EDM-760 Twin, JPI, California, USA, 2005 **| 7.** Pilot's Guide EDM-730, EDM-830, EDM-740, JPI, California, USA, 2005 **| 8.** Ultimate Bar Graph Engine Analyzer (UBG-16) Operating Instructions, Electronic International, Oregon, USA, 1997 **| 9.** Lycoming Operators Manual, Lycoming, USA, March 1973 **| 10.** Pilot's Guide, EzTrends, J. P. Instruments, 2006