Engine Fault Detection for Piston Engine Aircraft

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Abstract - Digital engine monitor can record vast amount of data in form of engine parameters from the aircraft piston engine. By analyzing these parameters it should be possible to detect majority of current or impeding engine problems. Statistical description of engine parameters together with rule based pattern recognition of catalogued graphic engine fault patterns shown as bar graphs on the engine monitor display may help detect abnormal engine conditions. Method for automatic analysis of engine monitor data and labeling potential problems is described.

I. Introduction

Almost all general aviation aircrafts (with the exception of business jets) are powered by engine–propeller combination. In most single-engine light aircraft, the power plant is a four-stroke reciprocating engine with a direct drive to a propeller. Aircraft piston engines are relatively reliable devices. Engine failures are rare, but do happen. In case of engine failure it is possible to land an aircraft, but this is very risky event, particularly if engine failure happen over inhospitable terrain, in IFR (instrumental) conditions or at night.

II. Piston Engine And Propeller Combination

Thrust necessary for flight is generated by engine-propeller combination.

A. Piston Engine

Piston engine is an economical source of power for small (general aviation) aircraft due to its power output, price and fuel consumption at cruise speed of a typical general aviation aircraft. Essentially it is a heat engine that uses one or more reciprocating pistons to convert pressure into a rotating motion. Most common aircraft piston engine are horizontally opposed, air-cooled four-, six- and eight-cylinder engines. Engines have old fashion but reliable fixed-timed dual magneto ignition systems (no use of electronics).

B. Propeller

Propellers are generally directly driven by an engine, although gearbox speed reductors exist on some higher power engines. Most training aircraft employ fixed-pitch propeller while complex aircrafts and trainers use constant speed propeller. Constant speed propeller is necessary to cope efficiently with this with variations in speed range and engine power. As aircraft speed increases, so does propeller efficiency, up to a peak. However, at faster speeds, efficiency reduces. By varying the pitch, it is possible to extend this maximum efficiency over a greater speed range. Also, as airplane climb higher, the density of the air decreases. To maintain speed, a coarser blade angle must be taken.

C. Engine-Propeller Power Management

Aircraft engine-propeller combination (with constant speed propeller) is controlled by three levers: thrust, propeller pitch and mixture. Thrust controls manifold pressure (MAP), propeller pitch controls RPM (revolutions per minute) and mixture controls fuel pressure and indirectly fuel flow. Manifold pressure (MAP) is the actual pressure in the inlet manifold in inches of mercury (Hg), measured by a sensor downstream of the throttle plate.

III. Engine Monitor

The main source of engine information available to pilot are several gauges indicating engine rotational speed (RPM, tachometer), oil pressure, oil temperature, exhaust gas temperature (EGT) and fuel flow. These gauges give very basic information about the engine condition. More advanced solutions exist today in form of engine monitors. 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), Fig. 1. Adequate skill is needed for correct engine monitor data interpretation. Beside engine condition monitoring, these engine monitors can be used for improved engine operation (fuel economy). Piston engine is not particularly efficient and only a small portion of the energy from combustion produces movement of the piston during the power stroke. The greatest part of energy passes into the exhaust pipe as hot gasses. By monitoring the temperature of exhaust gasses it is possible to assess the quality of the combustion process. Diminished efficiency of the

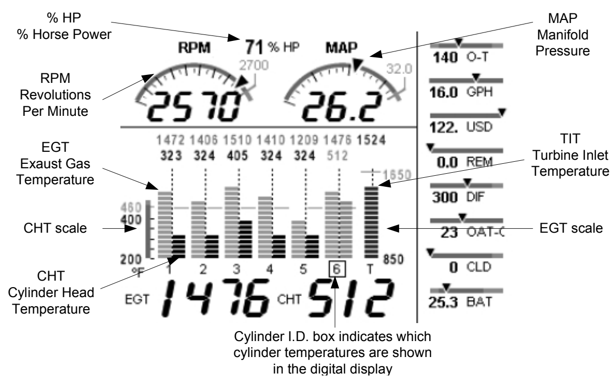

Figure 1. Engine monitor display (EDM 830)

TABLE I Monitored engine parameters

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*

combustion process that generates power indicates engine problems like low compression, non-uniform fuel distribution, faulty ignition, and clogged injectors, [1]. Engine parameters are collected from engine monitor probes installed on an engine. Engine monitor used in an experiment (EDM 830) records and calculates numerous engine parameters that are listed in Table I and shown in form of bar graph and digital display, Fig. 1. Parameters are displayed and recorded at the programmed interval (default setting is every 6 seconds). Depending on the monitored engine not all parameters are available. Other parameters (battery voltage, remaining fuel etc.) collected by the monitor are collected but are not relevant for consideration here. Example of engine monitor log is shown in Fig. 2. Graphical representation for main engine parameters through the duration of one whole flight is shown in Fig. 3 (upper curves represent *EGT*s and lower curves *CHT*s), [2]. Engine diagnosis charts supplied with the engine monitor describe engine fault patterns (shown

INDEX	TIME	E1	E2	E3	E4	E5	E6	C1	C2	C3	C4	C5	C6	T1	T2	OILT	DIF	CLD	OAT	CDT	IAT	BAT	FF	USD	RPM	MAP	HP	MA
0	15:40:58	636	641	896	944	859	986	188	134	154	182	206	201	726	608	87	350	0	20	25	21	13,8	3,0	0,4	994	18,5	18	
1	15:41:04	636	641	896	944	859	986	188	134	154	182	206	201	726	608	87	350	0	20	25	21	13,8	3,0	0,4	994	18,5	18	
2	15:41:10	626	651	896	944	859	986	193	136	154	187	210	205	726	608	87	360	0	20	25	21	13,8	3,0	0,4	1000	18,5	18	
3	15:41:16	638	651	896	951	866	993	196	138	157	191	214	208	735	618	89	355	0	20	25	21	13,8	3,0	0,4	1000	18,5	18	
4	15:41:22	660	660	896	951	866	993	200	138	157	195	217	211	744	628	89	333	0	20	25	21	13,8	3,0	0,4	1000	18,5	18	
5	15:41:28	654	652	903	951	866	993	203	141	159	198	220	214	744	628	91	341	0	20	25	21	13,8	3,0	0,4	1000	18,5	18	
6	15:41:34	654	652	903	951	871	993	205	141	159	202	223	217	744	628	91	341	0	20	25	21	13,8	3,0	0,4	1000	18,5	18	
7	15:41:40	654	652	908	951	876	993	209	144	161	205	226	220	744	635	91	341	0	20	25	21	13,6	3,0	0,4	1005	18,5	18	
8	15:41:46	662	660	908	951	876	993	211	144	161	208	229	222	750	635	93	333	0	20	27	21	14,0	3,0	0,4	1005	18,5	18	
9	15:41:52	655	669	908	959	876	998	214	146	163	211	231	225	750	641	93	343	0	20	27	21	14,0	3,0	0,4	1005	18,5	18	
10	15:41:58	655	651	908	959	876	998	217	148	163	214	234	227	756	646	95	347	0	20	27	21	14,0	3,0	0,4	1005	18,5	18	
11	15:42:04	655	656	908	959	882	998	219	148	166	217	237	230	756	646	95	343	0	20	27	21	14,0	3,0	0,4	1013	18,5	18	
12	15:42:10	647	669	916	964	882	998	222	150	166	220	239	232	756	646	95	351	0	20	27	21	14,0	3,0	0,4	1006	18,5	18	

Figure 2. Engine monitor log

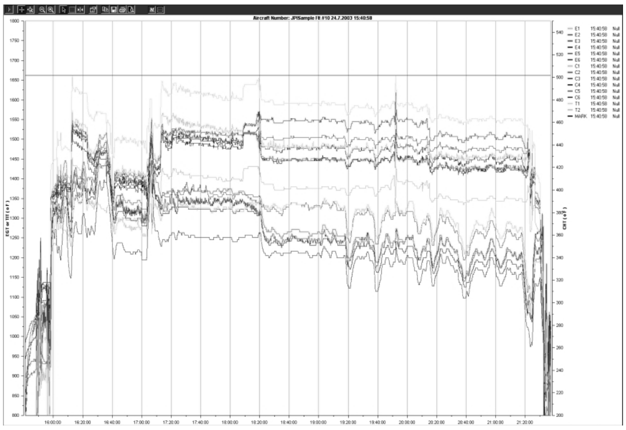

Figure 3. EzTrends engine parameter plots

in terms of bar graph on a display) can help diagnose various engine faults, [1]. There are 15 general patterns that indicate particular faults.

IV. METHOD FOR FAULT DETECTION

Proposed method is combination of statistical and pattern recognition approach. It preserves default engine monitor alarm limits but adds new alarm limits corresponding to current engine working regime and augments it all with rule based fault pattern recognition, Fig. 4. Method is intended for parsing engine parameters log after the flight. Great problem with advising fault detection method is due to very reliable aircraft engines. It is very difficult, with exception of large manufacturer and overhaul services, to obtain sufficient large sample of failed engines. On the other hand artificial failures can be produced (failure injection), but this process could harm the expensive engine (some failures would require destructive testing with high price tag), yet it will not cover all problems.

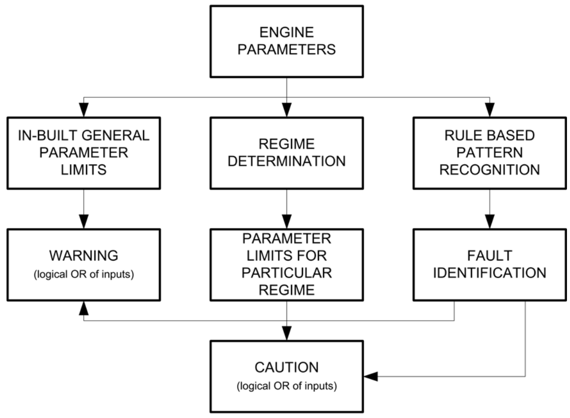

Figure 4. General description of the method

V. STATISTICS OF ENGINE PARAMETERS

Statistical analysis of engine parameters logs (included with EzTrends software: Flt#10 of duration 5.58 hours and Flt#11 of duration 3.69 hours, Continental TSIO-550?) was performed and Box-Wiskers plot was used for graphical representation of key values from summary statistics. Values represented in the summary are the mean, std. dev., minimum, maximum, 1th percentile and 99th percentile:

$$[\,\mu_{p_i}, \sigma_{p_i}, \min(p_i), \max(p_i), P1, P99\,] \tag{1}$$

The mean value for parameters p_i is determined by

$$\mu_{p_i} = \frac{1}{N_R}\sum_{j=1}^{N_R} p_{i,j} \tag{2}$$

and the standard deviation is determined by

$$\sigma_{p,i} = \sqrt{\frac{1}{N_R}\sum_{j=1}^{N_R}\left(p_{i,j} - \mu_{p,i}\right)} \tag{3}$$

where N_R is the number of records.

Percentile is the value of a variable below which a certain percent of observations fall. For example, the 99th percentile is the value below which 99% of the observations may be found. Percentiles are very suitable for exploring the distribution of number sets using various

TABLE II Engine parameters present in a log of analyzed engine

Parameter	Description
EGT 1-6	Exhaust Gas Temperature[1]
CHT 1-6	Cylinder Head temperature[1]
OIL TEMP	Oil Temperature[1]
TIT 1	Turbine Inlet Temperature[1]
TIT 2	Turbine Inlet Temperature 2[1]
CDT	Compressor Discharge Temperature
IAT	Intercooler Air Temperature
CDT - IAT	Intercooler cooling
RPM	Rotations Per Minute
MAP	Manifold Pressure
% HP	% Horse Power[2]
CLD	CHT Cooling Rate
DIF	EGT Span
FF	Fuel Flow

[1]included in a statistical summary (gray), [2]histogram of values determined

exploratory data analysis graphs (like Box-Wiskers plots) Parameters that have been present in available engine logs and are here considered are presented in Table II.

A. Analysis of the Whole Engine Log

Statistical results of engine parameters for the log that encompass duration of whole flight are presented in Table III and Fig. 5 (please note wide temperature scales and corresponding temperature ranges for various engine parameters). Maximal values correspond quite close to built-in (but modifiable) default alarm levels encompassing all engine regimes during a flight (one fits all approach), as shown in Table VI.

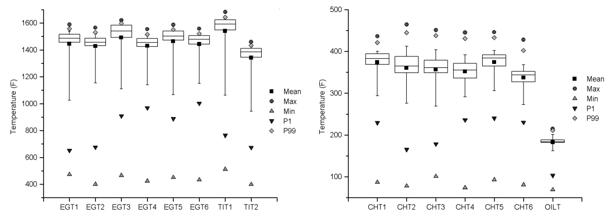

Figure 5. *EGT1-6*, *TIT1*, *TIT2*, *CHT1-6* and *OILT* for all regimes

TABLE III Statistical summary of engine parameters encompassing all engine regimes

Param.	Mean μ	Std.Dev.σ	Min	Max	P1	P99
EGT1	1445,3	167,9	473	1588	651,2	1558
EGT2	1427,4	146,3	400	1566	675	1531
EGT3	1491,4	145,9	466	1620	908	1599
EGT4	1429,5	109,1	424	1554	968,2	1515
EGT5	1463,7	139,1	451	1587	887	1553
EGT6	1442,6	111,6	433	1558	1002	1522
TIT1	1540,2	174,5	511	1682	764,4	1642,8
TIT2	1340,9	143,7	399	1459	673	1433
CHT1	373,6	35,3	87	436	229	421
CHT2	360,1	45,3	78	464	165,2	445
CHT3	356,1	42,5	101	451	178,4	438
CHT4	351,7	33,5	74	445	236	431
CHT5	374,1	33,2	93	446	240	433
CHT6	337,2	29,9	81	428	230	402
OILT	182,5	15,4	69	215	103,2	211
FF	10,17	3,41	1,3	27,8	3	22,5

B. Multiple Engine Regimes

In ideal case one would determine distribution of engine parameters for each engine working regime corresponding to various flight phases: engine run up, take-off, climb and full throttle operation cruise and descent. Engine, propeller and mixture combinations for various flight phases are presented in Table IV, [3].

TABLE IV Example of RPM/MAP power setting combinations for a typical GA aircraft

Flight phase	MAP	FF	Mixture	RPM range	Pitch Lever
Take off	28-30“	high	rich	2650-2700	fine
Climb	26-28“	high	BPM[1]	2600	fine
Cruise	20-24“	med.	BPM/ BEM[2]	1800-2400	medium -coarse
Appr.	18-22“	low	rich	1800-2400	med or out of CSU[3] range
Go around	as for takeoff				

[1]BPM – Best Power Mixture, [2]BEM – Best Economy Mixture, [3]CSU – Constant Speed Unit

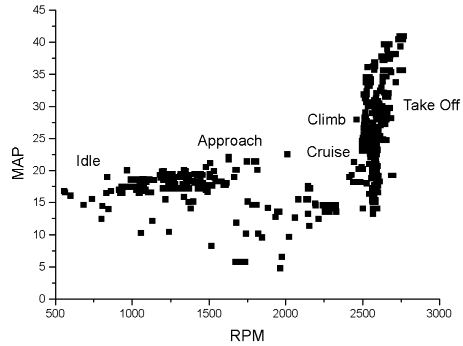

Figure 6. *RPM/MAP* combination for various flight phases

The concept of switching between multiple regimes is introduced to separate engine parameter statistics for each engine regime. One way to determine engine working regime would be from clustered *RPM/MAP* combinations, Fig. 6. However, in usual operations only small subset of these combinations is used, yet it may happen that for some reason pilot select unusual *RPM/MAP* combination lacking historical data in available engine logs (e.g. outside clustered areas). Because engine operation is of central consideration here, engine regimes are determined from calculated percent of the maximal horse power (% *HP*). This is simple and logical choice instead of using more complex multivariate clustering based techniques (e.g. using *RPM*, *MAP*, *OAT* and *FF*). % *HP* is already calculated by engine monitor from *RPM*, *MAP*, *OAT* and *FF*. Resulting percentage of Horse Power (% *HP*), is used as a proxy for determining engine regime. Fig. 7 illustrates calculated % *HP* as a function of RPM and MAP values. Histogram of statistical distribution for % *HP* is shown in Fig. 8. Same data presented in six bins corresponding to six engine regimes is shown in Fig. 9. Engine regime selection is shown in Table V and Fig. 10.

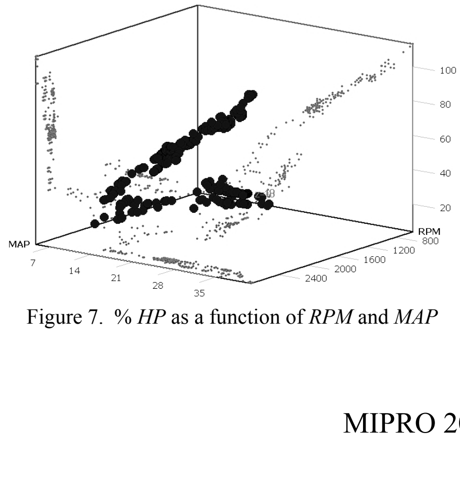

Figure 7. % *HP* as a function of *RPM* and *MAP*

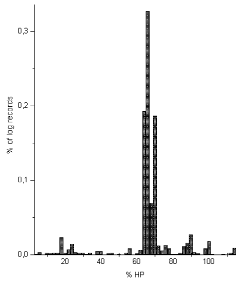

Figure 8. % *HP* histogram

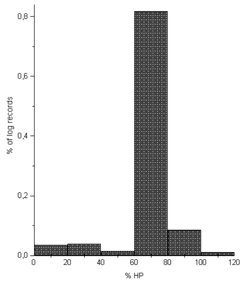

Figure 9. % *HP* histogram in 20% bins

TABLE V Engine regime selection by % *HP* value

% *HP*	Engine regime
0 – 19	1
20 – 39	2
40 – 59	3
60 – 79	4
80 – 99	5
100 - 119	6

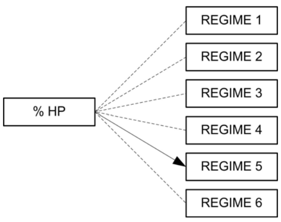

Figure 10. Engine regime selection using % *HP*

To counteract effect of short application of power bursts by engine throttle that don't have immediate effect on engine temperatures (that change more slowly), moving average of several samples (e.g. N=5) may be applied to calculated % *HP* values P_i as a form of low pass filter giving averaged power $\hat{P}$ and consequently regime r:

$$\hat{P}\frac{1}{N}\sum_{i=1}^{N}P_i \tag{4}$$

$$r_i = \left\lceil \frac{\hat{P}}{20} \right\rceil + 1 \tag{5}$$

Statistical plots engine parameters for various engine regimes are shown in Fig. 11-16. Dependence of engine parameters on calculated % *HP* (P_i) is clearly evident (please note different auto scales for temperature axis).

VI. ALARM LIMITS

The EDM has several programmable owner-programmable exceedance settings for all parameters. Exceedance warnings are both visual and aural. When a parameter falls outside normal limits, the display flashes its value and acronym. Once the parameter value returns within its normal limits, the flashing stops.

A. Default Alarm Limits

Default alarm limits are conservatively set (by JPI) below engine manufacturers (Lycoming and Continental) recommendations, Table VI. If a parameter gets out of its normal limits, the digital display will blink indicating the value and abbreviation of the problematic parameter. Because the temperature values of *EGT*s can assume different ranges depending on the current flight phase (climb, cruise) or engine run-up, monitor doesn't provide alarm limits for individual *EGT*s, it calculates the *DIF* parameter instead. The value for *DIF* is the difference between the hottest and coolest *EGT*s. This EGT span is important for monitoring the values of *EGT*s, [2]. Default alarm limits are set to encompass all flight regimes ("one fits all"). Engine monitor used in an experiment has default settings for limits shown in Table VI. Simple limit checking is used for exceedance warnings. Two limit values, thresholds, are present, a maximal value Y_{max} and a minimal value Y_{min}. A normal state is when

TABLE VI 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 900 °C
CLD		-60 °F/min -33 °C/min
DIF		500 °F 280 °C
MAP		32 inch Hg

$$Y_{\min} \le Y(t) \le Y_{\max} \tag{6}$$

Big advantage of limit checking is its simplicity and reliability, [4]. Maximal value Y_{max} and a minimal value Y_{min} are determined from parameter statistics

$$L_{L,i} < p_i < L_{H,i} \tag{7}$$

where

$L_{L,i}$ is low limit for parameter p_i
$L_{H,i}$ is high limit for parameter p_i
p_i is engine parameter i

Most parameters don't need lower limit and only high limit is used (e.g. temperature too high). Oil temperature and fuel flow need both limits (low oil viscosity al low temperature and abnormal fuel consumption). Alarm levels for warning alert (that require immediate crew awareness and corrective action) commonly set at the engine monitor are universal for all phases of flight and provide detection of serious faults.

B. Engine Regime Dependent Alarm Limits

Determination of the appropriate threshold could be quite difficult task [5, 6]. In this method it is supposed that record form the engine log should be closer examined if the value of engine parameter falls above value of 99% percentile or below value of 1% percentile if lower limit is used for that parameter (both rare events). This choice is experience based, considering the tradeoff in accuracy, [6]. Fine detection suitable for caution alert (corrective action may be required) is achieved by statistical analysis of engine parameters within each engine regime. Parameter range that is acceptable for one engine regime may be different for other regimes. Engine parameter statistics is collected and analyzed. Alarm limits are determined from extracted statistical data supplied in engine monitor logs. Limit values (1 and 99 percentiles) for parameters p_i and regime r are shown in Table VII. *OILT* and *FF* use both limits. Just upper limit is used for *EGT*, *TIT* and *CHT*.

$$L_{L,i,r} < p_i < L_{H,i,r} \tag{8}$$

$$p_i < L_{H,i,r} \tag{9}$$

where $L_{L,i,r}$ and $L_{H,i,r}$ are low and high limits for regime r.

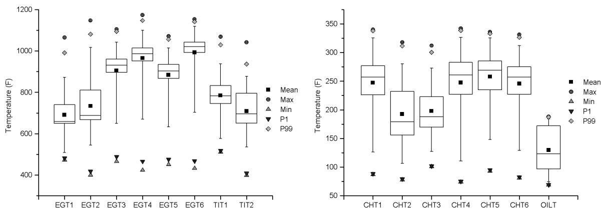

Figure 11. *EGT1-6*, *TIT1*, *TIT2*, *CHT1-6* and *OILT* for regime 1

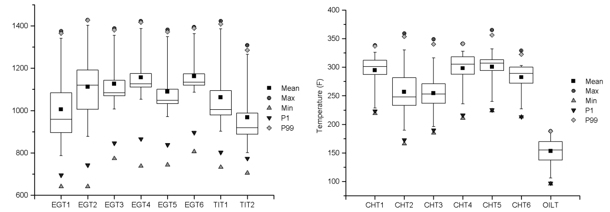

Figure 12. *EGT1-6*, *TIT1*, *TIT2*, *CHT1-6* and *OILT* for regime 2

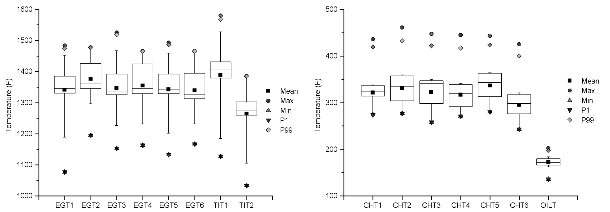

Figure 13. *EGT1-6*, *TIT1*, *TIT2*, *CHT1-6* and *OILT* for regime 3

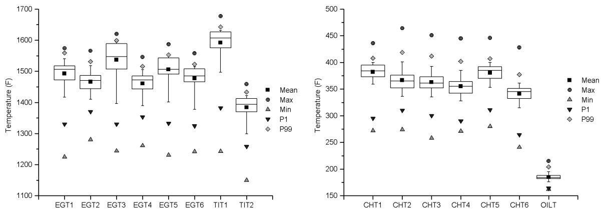

Figure 14. *EGT1-6*, *TIT1*, *TIT2*, *CHT1-6* and *OILT* for regime 4

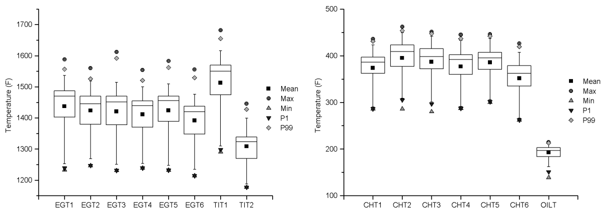

Figure 15. *EGT1-6*, *TIT1*, *TIT2*, *CHT1-6* and *OILT* for regime 5

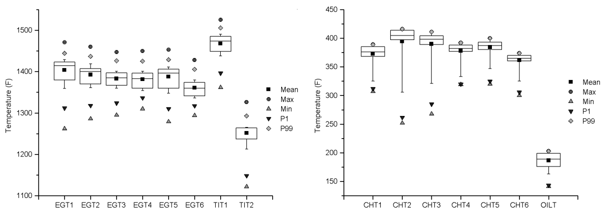

Figure 16. *EGT1-6*, *TIT1*, *TIT2*, *CHT1-6* and *OILT* for regime 6

VII. ENGINE FAULT PATTERNS

Engine monitor is capable of displaying EGT-CHT patterns suitable for fault detection. Patterns consist of bar graphs, darker bars represent EGT and lighter bars CHT values. Each pattern corresponds to one or more engine problems. Proposed pattern recognition technique employed in this method is rule based. This is due to rather precise fault pattern descriptions available in pilot's guide that comes with the engine monitor, [1]. There is also a lack of numerous real world patterns that would otherwise justify use of some statistical pattern recognition techniques. Rules are defined as descriptions in English language, usually one sentence and catalogued in manual. Following parameters (measured and calculated) are used in rules that describe conditions for fault pattern: EGT_{max}, EGT_{min}, CHT_{max}, CHT_{min}, *DIFF* and *RPM*. Here is a list of catalogued patterns (six cylinder engine), but now with derived simple mathematical description (conditions) suitable for program implementation. Resulting conditions are described in relations (10) - (21).

TABLE VII 1% and 99% percentile values for various engine parameters and engine regimes (used limits are shaded)

Param. p_i	Regime r											
	1		2		3		4		5		6	
	L_L	L_H	L_L	L_H	L_L	L_H	L_L	L_H	L_L	L_H	L_L	L_H
EGT1	482	991	695	1365	1077	1475	1330	1559	1239	1557	1312	1445
EGT2	418	1081	742	1427	1195	1477	1370	1531	1247	1526	1318	1437
EGT3	488	1094	846	1380	1153	1519	1330	1599	1231	1592	1324	1426
EGT4	466	1147	866	1417	1163	1466	1353	1516	1239	1521	1336	1425
EGT5	476	1056	838	1372	1133	1487	1333	1553	1232	1563	1310	1429
EGT6	468	1141	896	1389	1167	1465	1325	1523	1214	1530	1317	1406
TIT1	518	1030	802	1408	1127	1568	1382	1643	1298	1655	1396	1506
TIT2	409	936	773	1285	1033	1385	1258	1433	1177	1427	1148	1293
CHT1	88	338	223	337	274	415	295	408	286	431	312	389
CHT2	79	312	173	354	277	433	310	419	305	454	262	416
CHT3	102	300	190	340	258	422	300	412	297	448	285	411
CHT4	75	339	216	341	271	417	290	402	287	437	320	392
CHT5	95	333	225	356	280	423	311	407	302	442	325	400
CHT6	83	327	213	323	243	400	264	377	262	420	306	374
OILT	69	188	97	188	136	197	164	204	151	213	143	203
FF	1,4	4,5	3,4	9,2	6,5	11,7	8,2	13,4	10,9	22,3	21,7	27,8

1. 75° to 100° EGT rise for one cylinder during flight

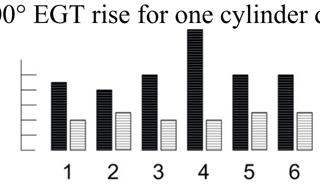

Figure 17. Pattern 1

$$\text{CAUTION if } abs(EGT_{max} - EGT_i) > 75 \text{ for any } i=1,\dots,6 \quad (10)$$

2. EGT increase or decrease after ignition system maintenance
   – not implemented (external information about maintenance is needed)
3. Loss of EGT for one cylinder

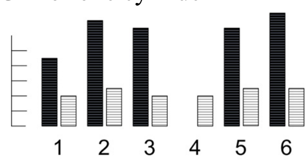

Figure 18. Pattern 3

$$\text{CAUTION if } EGT_{min} < 600 \quad (11)$$

4. Loss of EGT for one cylinder; no digital EGT
   – not implemented, imprecise log entry definition
5. Decrease of EGT for one cylinder

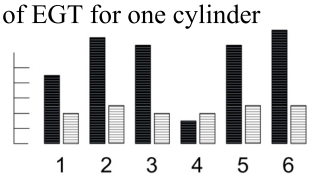

Figure 19. Pattern 5

$$\text{CAUTION if } 600 < EGT_{min} < 1000 \quad (12)$$

6. Decrease of EGT for one cylinder at low RPM

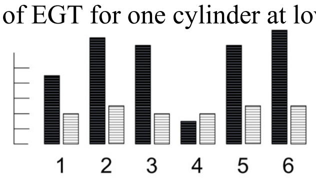

Figure 20. Pattern 6

$$\text{CAUTION if } DIFF > 500 \text{ AND } RPM < 1500 \quad (13)$$

7. EGT and CHT not uniform (injection engines only)

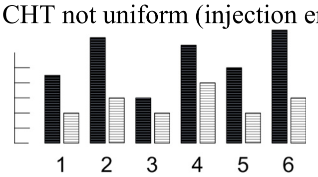

Figure 21. Pattern 7

WARNING if $(EGT_i/CHT_i)<3$ OR $(EGT_i/CHT_i)>6$ for any i=1,...,6 (14)

8. Decrease in EGT for all cylinders

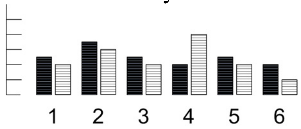

Figure 22. Pattern 8

WARNING if $EGT_i < 1200$ for all i=1,...,6 (15)

9. Slow rise in EGT, low CHT

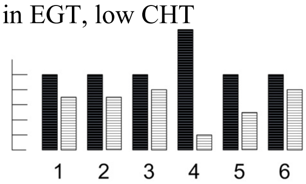

Figure 23. Pattern 9

WARNING if $EGT_i > 1600$ and $CHT_i < 300$ for any i=1,...,6 (16)

10. High CHT on cylinders on one side of engine

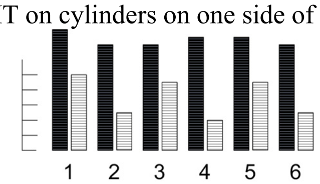

Figure 24. Pattern 10

WARNING if $\text{abs}(CHT_{\text{left}}-CHT_{\text{right}}) > 100$ *left*=2,4,6 *right* =1,3,5 (17)

11. Rapid rise in EGT/CHT of one cylinder

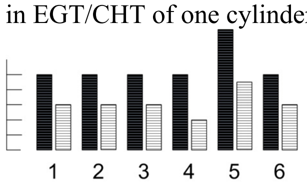

Figure 25. Pattern 11

WARNING if $EGT_i > 1650$ and $CHT_i > 400$ for any i=1,...,6 (18)

12. Sudden off scale rise for any or all cylinders

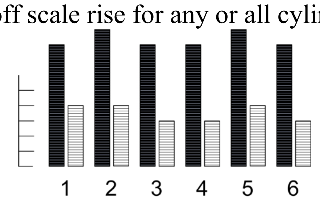

Figure 26. Pattern 12

WARNING if $EGT_{max} > 1650$ for any i=1,...,6 (19)

13. Loss of peak EGT - not implemented, leaning process
14. Decrease in peak or flat EGT response to leaning process - not implemented, leaning process (mixt. adj.)
15. Bellow 10,000 ft full throttle causes EGTs to rise – not implemented, 10,000 ft info needed
16. CHT more than 500º, EGT normal. Adjacent EGT may be low

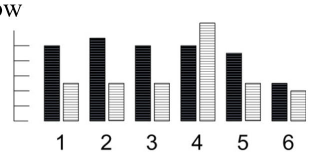

Figure 27. Pattern 16

WARNING if $CHT_{max} > 500$ AND $EGT_{max} < 1600$ (20)

17. Large DIFF at low RPM

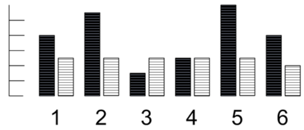

Figure 28. Pattern 17

WARNING if $DIFF > 500$ AND $RPM < 1500$ (21)

All records in the engine log could be checked for fault patterns using procedure and derived conditions:

```
for record=1 to last
{
  find EGTmax, EGTmin, CHTmax and CHTmin, get DIFF and RPM
  for i = 1 to Npatterns
    check conditions for pattern(i)
}
```

VIII. Conclusion

Proposed method combines default engine monitor limits, statistical analysis of engine parameters for different engine working regimes and rule based pattern recognition. Based on graphic presentation of available engine data percent of the maximal horse power (% *HP*) was chosen as a variable for regime selection. Engine parameter statistics were determined for all engine regimes and presented using exploratory data analysis Box-Wiskers plots. Method is primarily intended for parsing engine log after the flight. Build in default engine monitor alarm limits are preserved for the detection of severe engine problems and issuing warning alerts. Tighter limits are imposed on engine parameters for each particular engine regime and for detecting finer engine problems and issuing caution alerts. Upper limits are 99 percentile of engine parameters for a particular regime (for oil temperature and fuel flow additional 1 percentile is used for lower limits). Mathematical description for most fault patterns is produced from linguistic description and expert opinion. Such mathematical descriptions in terms of pattern conditions are suitable for rule-based pattern recognition. With larger scale statistics (including more flights) and determination of reliable thresholds (adding minimal parameter deviation periods) the method could be applied in real time with indications in a cockpit.

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