MULTIPLE REGIME BASED FAULT DETECTION of AIRCRAFT PISTON ENGINE

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ABSTRACT - *Graphic engine monitors have a capability of setting alarm limits for particular group of engine parameters. Due to large variation of parameters during normal engine operation provided alarm limits are set to values that include large acceptable deviations during a flight. It is possible to separate engine operation to several regimes and propose tighter alarm limits for each of regimes. With these tighter limits it may be possible to detect smaller engine problems earlier.*

Keywords: *aircraft, piston engine, engine monitor, regime switching, fault detection*

1. INTRODUCTION

Most general aviation airplanes are powered by gasoline piston engines. These engines are economical solutions for applications where low power (up to few hundred HPs) is required. Piston engine lack the reliability of a turbine engine (about seven times less reliable), but are relatively cheap to produce, operate and maintain. Introduction of digital engine monitors, both during operation and maintenance, may significantly increase the reliability of aircraft piston engines. Six cylinder aircraft piston engine that drives directly the propeller is shown in ***Figure 1***.

Figure 1 *Six cylinder aircraft piston engine*

2. GRAPHIC ENGINE MONITOR

Digital engine monitor is an instrument that monitors dozen of engine parameters that are related to engine combustion process, [1-5]. By accessing the quality of combustion process it is possible to detect most engine problems, [1-6]. Parameters are obtained by probes mounted on the engine, ***Figure 2***. Values of parameters are presented on the display graphically as vertical bars (separately

Figure 2 *Engine monitor probes*

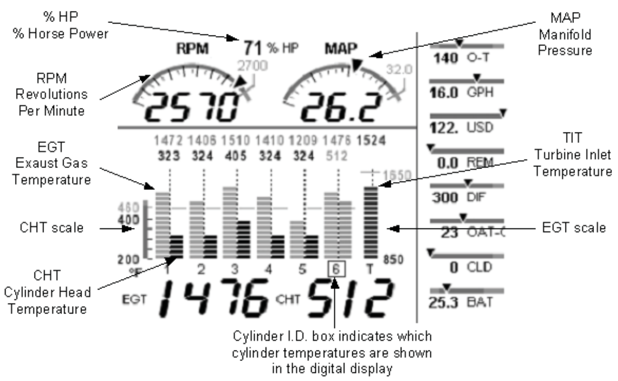

Figure 3 *Engine monitor with separate bars for EGT and CHT (JPI EDM 830)*

for each cylinder), ***Figure 3***, and recorded to built-in memory. Parameters are updated every several seconds (on JPI monitors default value is six seconds). Data can later be downloaded to the personal computer for analysis by maintenance personnel. Vertical bars on a display forms patterns that are catalogued in manuals, [2, 4, 5] for various fault conditions and can be used for visual recognition of potential engine problem.

2.1. ENGINE MONITOR PARAMETERS

Monitored engine parameters are listed in Table 1, composed from [5]. Most engine monitors use similar parameters (or some subset of these parameters, always including CHTs and EGTs).

***Table 1** Monitored engine parameters*

Parameter	Description
EGT	Exhaust Gas Temperature [1]
CHT	Cylinder Head temperature [1]
OIL TEMP	Oil Temperature [2]
OIL PRES	Oil Pressure [2]
TIT 1	Turbine Inlet Temperature 1[2]
TIT 2	Turbine Inlet Temperature 2 [2]
OAT	Outside Air Temperature
CDT	Compressor Discharge Temperature [2]
IAT	Intercooler Air Temperature [2]
CRB	Carburetor Air Temperature [2]
CDT - IAT	Intercooler cooling
RPM	Rotations Per Minute
MAP	Manifold Pressure
% HP	% Horse Power
CLD	CHT Cooling Rate [3]
DIF	EGT Span [4]
FF	Fuel Flow [2]

[1]one per cylinder, [2]optional, [3]fastest cooling cylinder, [4]difference between the hottest and coolest EGT

Some parameters (like EGT and TIT) react very quickly to changes in engine operation, some are slower (like CHT, several seconds delay) and some are quite slow (like OIL TEMP).

2.2. ALARM LEVELS

Engine monitors have adjustable alarm values for various parameters. Default values are shown in Table 2, modified from [4, 5]. Most parameters have only upper limit, but some have lower limit too (like OIL TEMP due to high oil viscosity at low temperature).

***Table 2** Default Engine Monitor Alarm Limits*

Measurement	Low Limit	High Limit
CHT		450 °F 230 °C
EGT [1]		1550 °F 843 °C [2]
OIL TEMP	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

[1]many engine monitors (e.g. JPI) don't have EGT alarm limit but DIF alarm limit instead, upper normal EGT value shown here, [2]on high performance aircraft, 1350 °F (732 °C) engines with less than 200 HP

3. MULTIPLE REGIME

During the flight engine operates in various regimes. Concept of regime switching is illustrated in Figure 4. Each regime has different CHT, EGT and TIT temperature range and different statistical properties of engine parameters.

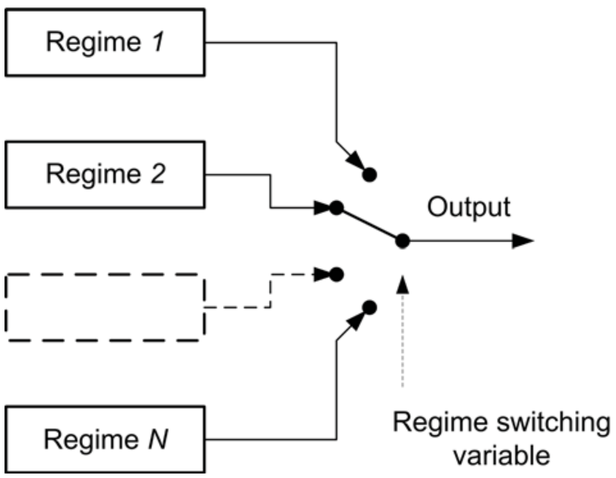

***Figure 4** Multiple regimes and regimes switching*

One may exploit statistical properties of each regime for fault detection.

3.1. CHOICE of the REGIME SWITCHING VARIABLE

To separate engine operation into several regimes, regime switching variable has to be introduced. Here are listed few choices for the regime switching variable [7, 8].

3.1.1. Revolutions per Minute (RPM)

Separation of engine regimes can be done based on the engine operating speed expressed in Revolutions Per Minute (RPM).

This simple solution has some shortcomings,

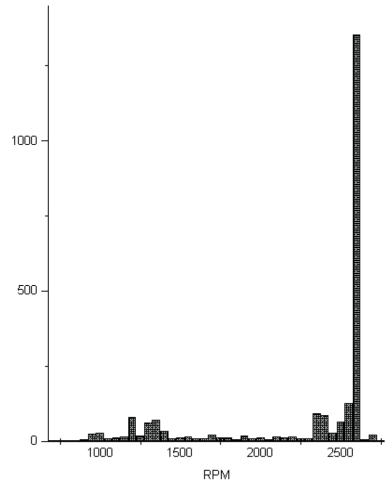

Figure 5 *RPM histogram*

because engine is exposed to different loads at same values of RPM during take-off, climb, cruise and descent, [7, 8]. Frequency histogram for RPM is shown in ***Figure 5***, and minimal and maximal values for RPM are shown in ***Table 3*** (from analyzing available engine log files of total duration 3,45 hours).

Table 3 *Minimal and maximal values for RPM*

	min	max
RPM	716	2732

Regime switching variable *r* for separation of regimes in RPM intervals is shown in Table 4. The 400 RPM bracket range is chosen for regime separation, considering that engine RPM will never be bellow 600 RPM.

Table 4 *Engine regimes as a function of RPM*

Engine regime	RPM
1	600-1000
2	1000-1400
3	1400-1800
4	1800-2200
5	2200-2600
6	>2600

3.1.2. Percent of Maximal Horse Power (%HP)

Percent of maximal Horse Power (%HP) seems as a better choice because it should more closely than RPM reflect the power engine produce, [7]. It considers Revolutions Per Minute (RPM), Manifold pressure (MAP), fuel flow (FF), outside air temperature (OAT) and sometimes pressure altitude. Because it includes MAP it is suitable for use on aircrafts with constant speed propeller. However %HP is often just one imprecise approximation of real situation. Some engine monitors gets this approximate value with much better accuracy then others depending on type of calculation and variables involved.

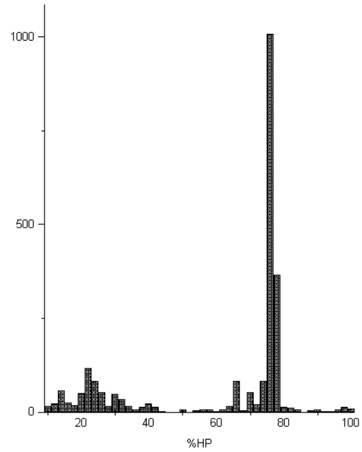

Figure 6 *%HP histogram*

Frequency histogram for %HP is shown in ***Figure 6***. Regime switching variable *r* for separation of regimes in 20% %HP intervals is given in (1) and ***Table 5***.

$$r = \left\lceil \frac{\%HP}{20} \right\rceil + 1 \qquad (1)$$

Table 5 *Engine regimes as a function of calculated % HP*

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

[1]Provision for values above 100%

The engine operates under different loads during the take-off, climb, cruise, descent and landing, [8]. These flight phases can't be accurately distinguished from engine parameters alone.

Most general aviation aircrafts still use cockpits with classical gauges and information about speed, altitude and vertical speed is not readily available in digital format. Approximate values can be obtained from commonly installed GPS receiver that supplies Ground Speed (GS) and geometric altitude instead of Indicated Airspeed (IAS) and barometric altitude).

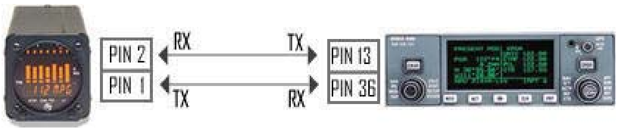

***Figure 7** Communication between graphic engine monitor and GPS receiver (JPI EDM 700/800 with a Bendix/King KLN 90/90A/90B) - JPI Instruments*

Communication between graphic engine monitor and GPS receiver is shown in ***Figure 7***. Following flight phases can be used for regime separation: engine run-up, take-off, climb, cruise, descent and landing as listed in ***Table 6***, [8]

***Table 6** Engine regimes as flight phases*

Engine regime	Phase
1	Run-up
2	Taxi
3	Take-off
4	Climb
5	Cruise
6	Descent
7	Landing[1]

[1]Not included in analysis due to very short duration, small number of records in engine logs and low load on engine.

Separation of flight phases based on GPS data and RPM is shown in ***Table 7***, [8]. Vertical Speed (VS), v, is calculated from successive altitudes h_{ti} and h_{ti+1}, at moments t_i and t_{i+1}, (2).

$$v = \frac{Alt_{t_{i+1}} - Alt_{t_i}}{t_{i+1} - t_i} \qquad (2)$$

***Table 7** Flight Phase Determination for Constant Speed Propeller*

Phase	Speed kn	Alt.ft QFE[1]	Vertical speed (v) ft/min	RPM	MAP[3]
Engine run-up	0[2]	0[2]	0[2]	800-1000	
Taxi	< 20	0[2]	0[2]	800-1500	
Take-off	< 45	0[2]	0[2]	2300+	
Climb	> 45	> 0	> 200	2000+	33-35
Cruise	> 45	> 0	200<v<200	1800-2700	32
Descent	> 45	> 0	v < -200	< 1800	18-24
Landing	< 45	0[2]	0[2]	< 1200	

[1]height above a specific aerodrome or ground level, [2]in practical considerations some tolerance must be allowed instead of precise value of 0, [3]approximative values

Separation of flight phases in terms of IF-THEN rules is shown bellow. Landing phase is not considered here due to very short duration (several seconds) and low engine load, [8].

IF SPEED < 3 AND 800< RPM <1700[1] Engine run-up
IF 3< SPEED <20 AND 30< VS <30[2] AND RPM <1500 Taxi
IF 3< SPEED <45[3] AND 30< VS <30[2] AND RPM >2300 Take-off
IF SPEED >45[3] AND VS >200 AND RPM > 2000 Climb
IF SPEED >45[3] AND -200< VS <200 Cruise

IF SPEED >45[3] AND VS < -200 Descent

[1]Recommended values for run-up are bellow 1500, value of 1700 is set after analyzing available logs, [2]In real world small margin of error (e.g. 30 ft/min due to GPS altitude error) must be allowed around value of 0 valid for ideal case, [3]Compromise value to allow for strong headwinds.

3.2. CHOICE of PARAMETERS for FAULT DETECTION

There exist numerous possibilities for selecting parameters that should be checked against predefined limits. One solution is to use all CHTs, EGTs (there is one for each cylinder), and TIT, (3).

$$C_i, E_i, T_j \qquad i=1, \dots, N_C \qquad j=1, \dots, N_T \tag{3}$$

where N_c is the number of cylinders, N_T turbos.

This considers differences among cylinders but results in sizable number of parameters and corresponding limits. Another solution is to use just extreme values of CHTs and EGTs plus TIT, (4)-(7):

CHT_{min}, CHT_{max}, EGT_{min}, EGT_{max}, TIT

$$C_{\min} = \min(C_i) \qquad i = 1, \dots, N_C \tag{4}$$
$$C_{\max} = \max(C_i) \qquad i = 1, \dots, N_C \tag{5}$$
$$E_{\min} = \min(E_i) \qquad i = 1, \dots, N_C \tag{6}$$
$$E_{\max} = \max(E_i) \qquad i = 1, \dots, N_C \tag{7}$$

Engine material is primarily sensitive to high temperatures, so one can discard minimal values and following parameters remain:

CHT_{max}, EGT_{max} with variables C_{max} and E_{max}.

Fault patterns on a display of engine monitor (various patterns of CHT and EGT bars) are heavily related to CHT and EGT span:

CHT_{span}, EGT_{span} with variables C_{span} and E_{span}.

Unusual CHT_{span} and/or EGT_{span} are also related to most fault patterns.

Oil temperature is included as vital engine parameter. It has both lower and upper limit:

OIL TEMP with the variable O_T

Oil pressure is also includes:

OIL PRES with the variable O_P

Parameters used in fault detection are listed in Table 8.

Table 8 *Parameters under consideration for fault detection*

Parameter	Variable	Description
CHT_{max}	C_{max}	Maximal CHT
EGT_{max}	E_{max}	Maximal EGT
CHT_{span}	C_{span}	Difference between maximal and minimal CHT
EGT_{span} (DIF)	E_{span}	Difference between maximal and minimal EGT
TIT 1	T_1	Turbine Inlet Temperature 1
TIT 2	T_2	Turbine Inlet Temperature 2
OIL TEMP	O_T	Oil Temperature
OIL PRES	O_P	Oil Pressure

4. STATISTICAL PROPERTIES of ENGINE PARAMETERS

Instead of using simple limit checkers one is tempted to use statistical distribution of engine parameters for fault detection but it is not simple endeavor, [9].

4.1. ANALYSIS of LOG FILES

Simple statistical analyses were performed on three engine monitor log files that are included with the EzTrends2 software: Flt#49 of duration 2.57 hours, Flt#56 of duration 0.43 hours and Flt#61 of duration 0.45 hours. All files are from the same, six cylinder, 280 HP turbonormalized Continental engine TSIO-550-G, belonging to 2007 Mooney M20TN Acclaim aircraft, N257TM, with no known faults present. Probability distributions of parameters for fault detection C_{max}, E_{max}, C_{span}, E_{span}, T_1, T_2, O_T and O_P in form of frequency histograms are shown in ***Figures 8-15***. Empirical probability distributions have several peaks and fat tails. As such they are too complicated for simple fitting to common mathematical distributions (like Gaussian or even mixture of Gaussians).

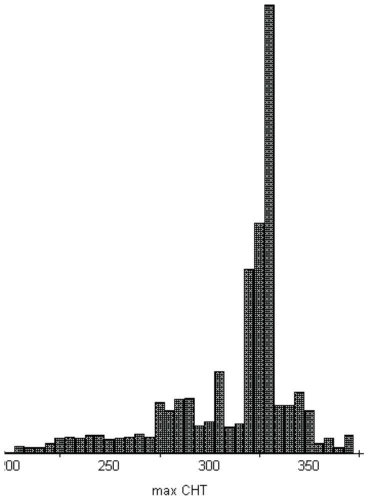

Figure 8 *C_{MAX} histogram*

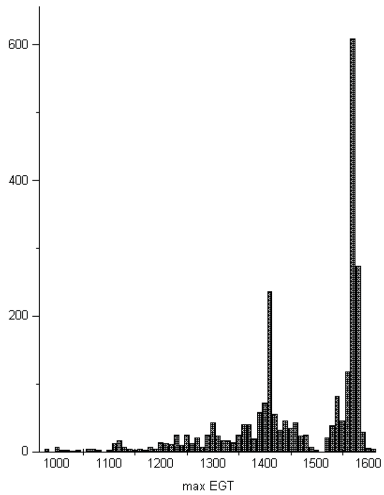

Figure 9 *E_{MAX} histogram*

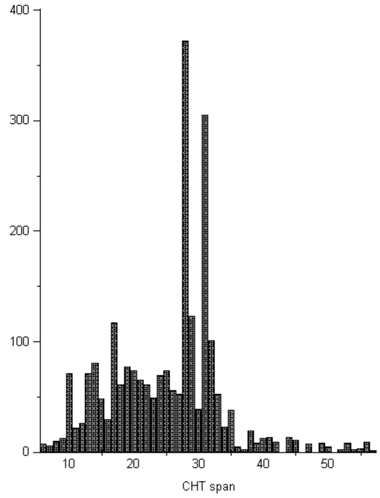

Figure 10 *C_{span} histogram*

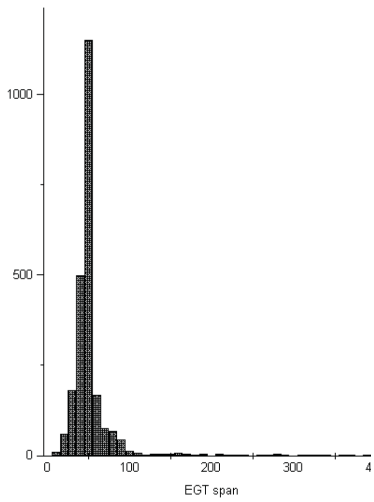

Figure 11 *E_{SPAN} histogram*

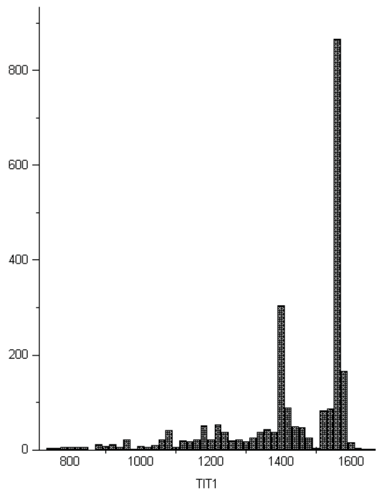

Figure 12 *T_1 histogram*

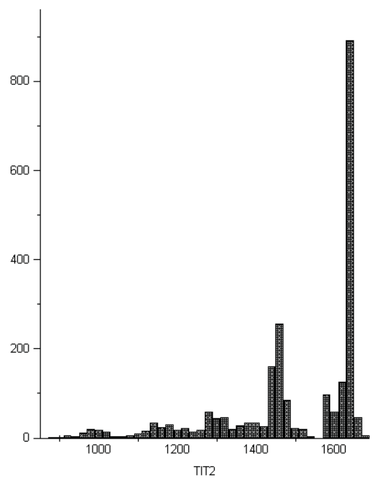

Figure 13 *T_2 histogram*

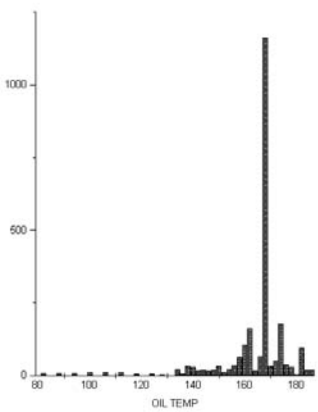

Figure 14 *O_T histogram*

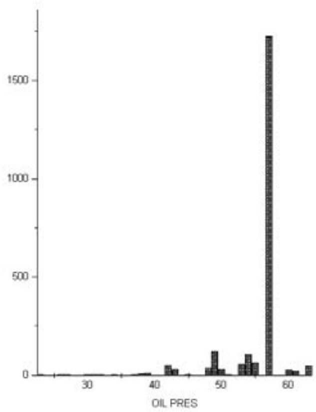

Figure 15 *O_P histogram*

4.2. STATISTICAL SUMMARY in FORM of PERCENTILES

One simple solution to previous problem is use of statistical summary in form of percentiles, [7-9]. Percentile is the value of a variable below which a certain percent of observations fall. The 99th percentile is the value below which 99% of the observations may be found. Calculation of percentile values is included in almost all statistical packages.

4.3. STATISTICAL SUMMARY of SELECTED PARAMETERS for ALL REGIMES

Statistical summary that is calculated from available engine monitor log files and includes all engine regimes is shown in ***Figure 16*** and ***Table 9***.

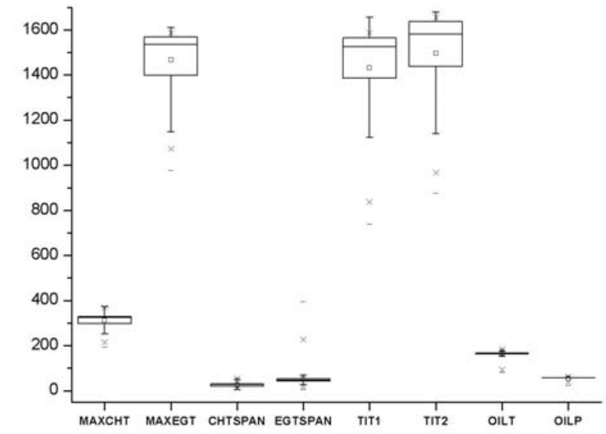

Figure 16 C_{max}, E_{max}, C_{span}, E_{span}, T_1, T_2, O_T and O_P

Table 9 *Statistical summary for all regimes*

All regimes				
	min	max	P_1	P_{99}
C_M	195	372	215	368
E_M	977	1610	1072,1	1587
C_S	6	57	8,77	52,2
E_S	6	395	18	229,4
T_1	739	1655	837	1588,2
T_2	876	1679	967,5	1656
O_T	81	185	93	183
O_P	23	63	39	63

4.4. STATISTICAL SUMMARY of SELECTED PARAMETERS for SEPARATE REGIMES

In a similar manner statistical summaries are calculated from available engine monitor logs, but this time engine regime separation is involved. Statistical summaries are presented here for all three choices for regime switching variable (RPM, %HP and flight phase). Same three engine monitor logs were analyzed as in previous section.

4.4.1. Rotations Per Minute (RPM)

Regime separation was done according to **Table 4**. Statistical summary is presented in **Table 10**.

Table 10 *Statistical summary for RPM*

Regime 1 600-1000 RPM				
var	min	max	P_1	P_{99}
C_M	195	259	195	258,4
E_M	984	1206	984	1206
C_S	16	26	16	25,76
E_S	64	324	64	322,2
T_1	746	968	747,0	966,7
T_2	903	1029	904,0	1028,9
O_T	81	168	81	167,6
O_P	23	60	23	60
Regime 2 1000-1400 RPM				
var	min	max	P_1	P_{99}
C_M	209	331	212,2	328
E_M	977	1401	1000,2	1385,2
C_S	6	24	8	24
E_S	25	395	26	364,8
T_1	739	1351	767,4	1265,6
T_2	876	1379	902,8	1349,7
O_T	87	171	87	171
O_P	37	60	38	60
Regime 3 1400-1800 RPM				
var	min	max	P_1	P_{99}
C_M	215	331	215,6	329,2
E_M	1164	1494	1185,2	1489,9
C_S	10	27	10	27
E_S	20	389	24,13	357,7
T_1	910	1437	918,9	1428,7
T_2	1030	1496	1041,8	1491,3
O_T	123	183	129,5	180,1
O_P	43	57	43	57
Regime 4 1800-2200 RPM				
var	min	max	P_1	P_{99}
C_M	216	348	217,0	346,0
E_M	1139	1477	1187,3	1474,0
C_S	9	30	10,02	30
E_S	13	194	15,04	157,0
T_1	1069	1439	1074,8	1435,6
T_2	1146	1478	1162,0	1477,3
O_T	155	185	155	185
O_P	49	61	49	61
Regime 5 2200-2600 RPM				
var	min	max	P_1	P_{99}
C_M	222	372	222	360,6
E_M	1214	1610	1317	1586,3
C_S	6	49	6,7	47
E_S	6	91	13,7	64,6
T_1	1146	1620	1281	1583
T_2	1228	1677	1325	1649,6
O_T	143	185	156	185
O_P	49	63	54	63
Regime 6 2600+ RPM				
var	min	max	P_1	P_{99}
C_M	238	371	298,24	371
E_M	1277	1609	1388	1591
C_S	7	57	14	55
E_S	30	83	39	70,16
T_1	1288	1655	1387	1595,4
T_2	1322	1679	1439	1658
O_T	149	185	162	177
O_P	54	63	55	63

4.4.2. % of maximal Horse Power (%HP)

Regime separation was done according to Table 5 and shown in Table 11.

Table 11 *Statistical summary for %HP*

Regime 1 0-19 %HP				
var	min	max	P_1	P_{99}
C_M	195	307	195	307
E_M	977	1405	980,8	1375,6
C_S	8	26	8	24,1
E_S	20	395	26,65	389,3
T_1	739	1293	745,7	1276,9
T_2	876	1371	877,9	1339,7
O_T	81	171	81	171
O_P	23	60	23	60
Regime 2 20-39 %HP				
var	min	max	P_1	P_{99}
C_M	215	352	219	331,52
E_M	1202	1494	1220	1476,9
C_S	6	30	6	28
E_S	6	194	13	100,13
T_1	1016	1465	1067	1434,4
T_2	1113	1504	1123,7	1469,1
O_T	105	185	105	185
O_P	42	61	42	57,52
Regime 3 40-59 %HP				
var	min	max	P_1	P_{99}
C_M	239	359	239	359
E_M	1139	1477	1139	1477
C_S	10	28	10	28
E_S	30	79	30	79
T_1	1069	1474	1069	1474
T_2	1146	1492	1146	1492
O_T	161	185	161	185
O_P	49	63	49	63
Regime 4 60-79 %HP				
var	min	max	P_1	P_{99}
C_M	231	372	275	371
E_M	1214	1610	1388	1591
C_S	6	57	12	53
E_S	22	91	30	60
T_1	1146	1655	1387	1594,1
T_2	1228	1679	1434,95	1658,05
O_T	143	185	156	181
O_P	49	63	55	57
Regime 5 80-99 %HP				
var	min	max	P_1	P_{99}
C_M	236	365	236,1	364,85
E_M	1277	1500	1278,65	1499,6
C_S	7	25	7	25
E_S	30	83	30	83
T_1	1288	1495	1289,7	1495
T_2	1322	1535	1324	1534,6
O_T	149	185	149,35	185
O_P	54	63	54	63
Regime 6 100-119 %HP (just one record)				
var	min	max	P_1	P_{99}
C_M	323	323	323	323
E_M	1493	1493	1493	1493
C_S	12	12	12	12
E_S	32	32	32	32
T_1	1495	1495	1495	1495
T_2	1535	1535	1535	1535
O_T	161	161	161	161
O_P	63	63	63	63

4.4.3. Flight Phase (determine with GPS)

Regime separation was by IF-THEN rules following Table 7 and shown in Table 12.

Table 12 *Statistical summary for flight phases*

Regime 1 Run-up				
var	min	max	P_1	P_{99}
C_M	195	328	198,1	326,2
E_M	1109	1494	1109	1484,6
C_S	8	26	9	24
E_S	25	173	26	170
T_1	888	1437	895	1422,4
T_2	966	1496	966	1469,1
O_T	81	165	81	165
O_P	39	60	39	60
Regime 2 Taxi				
var	min	max	P_1	P_{99}
C_M	206	331	207,7	331
E_M	1003	1389	1071,4	1379,7
C_S	6	24	7,16	24
E_S	27	189	27	187,8
T_1	788	1262	835,6	1261,4
T_2	936	1355	962,7	1348,6
O_T	105	165	105	165
O_P	23	57	34,02	57
Regime 3 Take-off (6 records)				
var	min	max	P_1	P_{99}
C_M	289	341	289	341
E_M	1352	1463	1352	1463
C_S	6	25	6	25
E_S	38	48	38	48
T_1	1341	1452	1341	1452
T_2	1372	1500	1372	1500
O_T	143	170	143	170
O_P	55	63	55	63
Regime 4 Climb				
var	min	max	P_1	P_{99}
C_M	239	372	244,4	371
E_M	1369	1581	1379,1	1579
C_S	7	56	8,69	56
E_S	19	83	30	79,31
T_1	1327	1577	1336	1571,6
T_2	1354	1650	1378	1648,3
O_T	160	185	160	185
O_P	54	63	54	63
Regime 5 Cruise				
var	min	max	P_1	P_{99}
C_M	206	371	238	350
E_M	998	1610	1270,3	1591,3
C_S	7	57	14,84	45
E_S	10	309	30	79,16
T_1	754	1655	1241,8	1599
T_2	903	1679	1288,5	1660
O_T	149	185	160	181,2
O_P	30	63	49	57
Regime 6 Descent				
var	min	max	P_1	P_{99}
C_M	209	371	215,6	345
E_M	977	1587	1002,1	1581
C_S	6	53	6	34
E_S	6	395	13	363,0
T_1	739	1583	772,5	1574,8
T_2	876	1659	922,9	1642
O_T	149	185	154	185
O_P	27	63	38	61

5. METHOD for FAULT DETECTION

Method for fault detection is illustrated in Figure 17. It incorporates usual common and well documented limits defined in ***Table 2***, [4, 5, 10], or extremes from ***Table 9***, for all regimes intended for detection of more severe engine problems with the addition of regime specific limits for each engine regime used for detection of smaller problems.

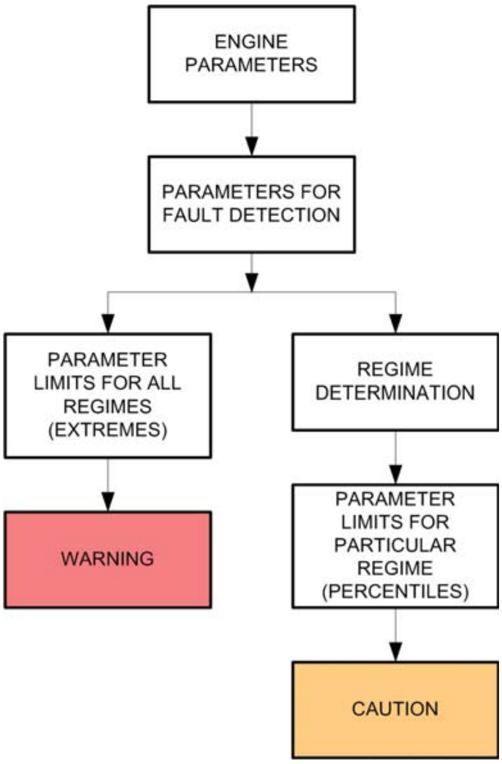

Figure 17 *Method for fault detection*

Quite often these small problems precede larger and more severe problems. Percentiles from statistical summaries are chosen as limits for particular engine regime. Warning alert (indicate a critical condition and require immediate action) is implemented using simple limit checkers, (8), [11], applied to measured engine parameters. Values for limits are shown in Tables 2 and 9 (minimal and maximal values, not percentiles)

$$L_{L,i} < p_i < L_{H,i} \qquad (8)$$

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

Limit checkers can now be applied to all engine regimes, (9), with separate limits for each regime, as shown in ***Tables 10-12***. It enables placement of tighter limits to engine parameters that are appropriate for particular engine regime and suitable for detection of smaller problems and issuing caution alert (require timely corrective action).

$$L_{L,i,r} < p_i < L_{H,i,r} \qquad (9)$$

where

$L_{L,i,r}$ is low limit for parameter p_i in regime r
$L_{H,i,r}$ is high limit for parameter p_i in regime r

5.1. ADJUSTING SENSITIVITY for FAULT DETECTION

Percentiles, while easy to determine, are too sensitive for setting alarm limits. With parameters update rate every six seconds (which translates to 600 engine log records per hour) each parameter on a healthy engine will exceed corresponding percentile limit several (typically six) times during one hour. The more parameters are under consideration, the more often some of them will exceed some of limits. This would result in spurious alerts. To address this problem limits can be combined with number of limit exceedances, Figure 18. Combining percentile limits and the number of limit exceedances within a specified time frame, appropriate sensitivity for distinguishing between sporadic and problematic frequent events, could be achieved, [8, 9].

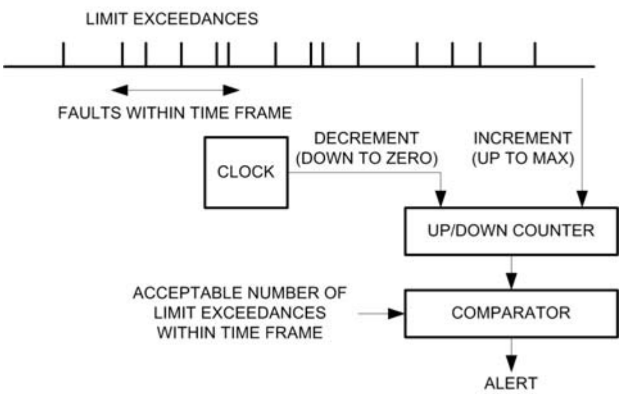

Figure 18 *Permitted number of threshold exceedances within a specified time frame*

6. CONCLUSION

One fits all alarm limits commonly found in engine monitors may put too wide limits on acceptable engine parameters and hence fail to detect smaller engine problems on time. Method for fault detection is presented that combine default limits and regime dependent limits. Detection of severe problems rely on default and extreme (minimum, maximum) limits set common for all engine regimes while detection of smaller problems is achieved using regime specific percentile limits. With the use of multiple regimes, new, tighter limits are introduced suitable to each particular regime. Three regime switching strategies are presented with statistical summaries of parameters in forms of percentiles that can be used for limit checking. Advantage of RPM as regime switching variable lies in its simplicity of implementation as it is readily available from engine monitor. However RPM is just a rough approximation of real engine load. Better choice is use of %HP as it is better related to current engine load. Nonetheless, %HP is also just an approximation of real value, sometimes better, sometimes worse, depending on engine monitor used. Use of flight phase for regime determination is more closely related to real engine load but is cumbersome to calculate from GPS data (most general aviation cockpits lack glass cockpit for simple extraction of groundspeed, indicated speed and barometric altitude). Multiple engine regime separation and corresponding limits may be considered when designing new generation of engine monitors.

7. REFERENCES

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