Walter M337 AK engine monitoring by system EDM-800 in operation of Air Training and Education Centre

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Abstract: *This paper describes the process of the M337 engine monitoring by the Engine Data Management 800 which is mounted on six aircraft of Air Training and Education Centre. This is the most advanced and accurate piston engine-monitoring system on the market that uses the latest microprocessor technology to monitor critical engine parameters in order to measure parameters as cylinder head temperature and exhaust gas temperature to evaluate each cylinder performance alone. These parameters are monitored during these flight regimes – take off, climb and cruise. Monitoring of the mentioned parameters will help us to increase the economy of the aircraft and also its operation's reliability.*

Key Words: *piston engine, EDM-800, Exhaust Gas Temperature, Cylinder Head Temperature*

1. INTRODUCTION

Air Training and Education Centre is located at the international Airport Zilina– Dolny Hricov, in the north-western part of Slovak Republic. The Flight school of University of Zilina was established in 1974 as the only civil school in former Czechoslovakia with the aim to provide civil pilot training. Air Training Centre as an independent organisation was established on 1st September 2002 in line with JAR-FCL 1.

Nowadays, the Air Training and Education Centre provides flight training up to ATP licence. The University of Zilina is a holder of the Certification on Flight Training Organisational approval (SK.ATO.01) in accordance with the JAA/EASA standards and aircraft maintenance centre approval (SK.MF.006, SK.MG.025). It also provides specialised courses such as, courses for Slovak Air Force, Security courses – NSC, and ATC-ATCO (Phase I/II) courses. Air Training and Education Centre uses both, single and twin engine aircraft for professional pilot training. This paper deals with the selected types of aircraft (with M337 engine) where EDM-800 monitoring system is installed for the purpose of monitoring the critical engine parameters, focusing on EGT (Exhaust Gas Temperature) and CHT (Cylinder Head Temperature) analysis.

2. WALTER M337 AK ENGINE OVERVIEW

Air Training and Education Centre uses these airplanes powered by M337 engine – Zlin 43, Zlin 142 and L-200D Morava for the pilot training course. More precisely we refer to the following aircraft, registered as: Z43 OM-KOZ, Z43 OM-LOW, Z142 OM-KNO, Z142

OM-PNU, Z142 OM-SNY and Z142 OM-UNA. For the purpose of this research we will use just Zlin 43 aircraft. The Avia M 337 originally Walter M337 engine (Figure 1) is an inverted six-cylinder air-cooled inline piston engine. It was developed as a six-cylinder derivative of the four-cylinder M332 engine.

It was made by the Czechoslovak company and went into production in 1960. An un-supercharged version of the M337 is designed M137, in 1964 the production was transformed to Avia company and in 1992 to LOM Prague – the main designer of inverted piston engines.

Figure 1. Illustration of the Zlin 43 aircraft – left M337 engine - right (Taylor, 1980)

“The first four-cylinder engine M332A was launched in 1992 and later, its derivation M332A has become the engine M332 AK which has no time limitation for inverted flight. The redesigned engine oil system enables, during inverted flight, back oil direction into oil tank conformable to M337 AK engine” (Tizek, 1992).

In addition, M337 engine is used for training aircraft for flight school or for commercial small, light-weight aircraft. The advantage of this engine is that it is characterised by a small frontal area, low weight, economic efficiency and simple maintenance.

Table 1 below illustrates the basic features of different variants of M 337 engine.

Table 1. Overview of the variants of the M337 engine (Taylor, 1980)

Variants	**Characteristic feature**
M 337 A	Basic supercharged engine (not for aerobatics purpose)
M 337 R	Modified for pusher installation
M 337 AK	Modified oil system (use for unlimited inverted flying, also *snap* aerobatics permitted
M 337 AK1	M 337 AK fitted with alternator instead of generator
M 337 B	Increased maximum running speed (3000 rpm) and power (173 kW)
M 337 BK	Aerobatic version of M 337 B
M 337 C	Increased compression ratio to 185 kW

According to (Taylor, 1980) general specifications of the M337 engine are illustrated in Table 2 below.

Table 2. Overview of the general characteristics of M337 (Taylor, 1980)

General characteristics		**Components**		**Performance**	
Type	6-cylinder inverted air-cooled supercharged inline engine	*Valve train*	2 camshaft operated valves per cylinder, sodium filled exhaust valve	*Power output*	157 kW at 2,750 rpm (take-off)

Bore	105 mm	*Supercharger*	Centrifugal		
Stroke	115 mm	*Fuel system*	Low-pressure fuel injection		
Displacement	5.97 L	*Fuel type*	Min 72-78 Octane		
Length	1,410 mm	*Oil system*	Dry sump pressure system		
Width	472 mm	*Cooling system*	Air cooled		
Height	628 mm				

EDM-800 MONITORING SYSTEM

EDM-800 (Figure 2) is made by J.P. Instruments, Inc. one of the instruments leading producers in this field. The system has been installed on selected aircraft of the Air training and Education Centre (Zlin 43, Zlin 142) in order to measure parameters of the engine and also to increase safety and efficiency of pilot training. The reason to choose this instrument was linked to the need of the instrument that is able to work in the background without affecting the other primary instruments.

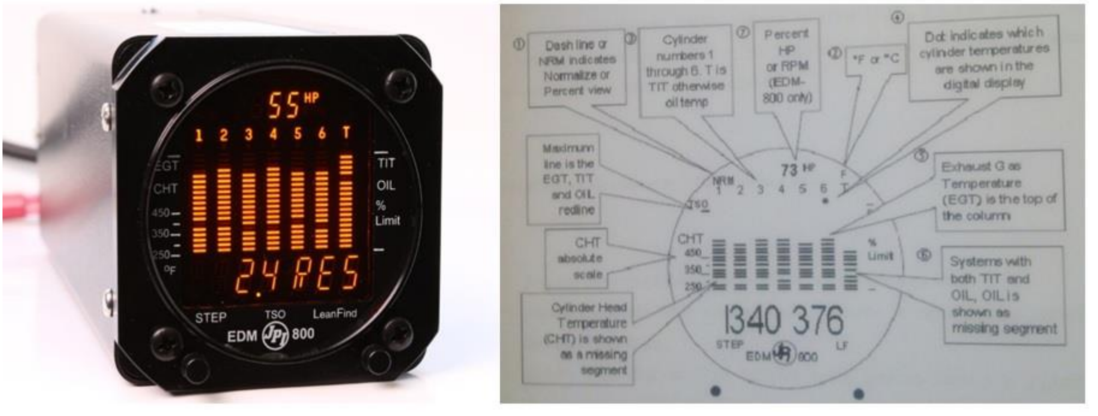


Figure 2. Illustration of the monitoring system EDM-800 instrument [author]

This system is the most advanced instrument ever produced for piston engine-monitoring. It is able to monitor 29 functions every 6 seconds for up to 25 hours or even every minute for 550 hours.

The instrument later records those parameters in a set time interval from 6 to 500 seconds. Automatically, if the monitored parameters exceed the limits, the pilot is warmed by a special signal.

This system provides important information to the user regarding EGT and CHT for all cylinders (the data is shown on graphical and digital displays). These two parameters will be important for the purpose of our research, though the system is able to monitor other parameters[1], such as oil pressure and temperature, compressor discharge temperature, turbine inlet temperature, OAT, MAP or RPM.

[1] J.P. Instruments Inc. produces many variants of EDM, such as EDM 700, 711 or 800. The product features are illustrated in *Table 3*.

Table 3. Overview of the basic features of EDM-800 monitoring system (Inc., 2007)

Feature of EDM-800
Hands-free, automatic scanning (711: primary only)
All programming done from the Front Panel
Lean Find TM finds the first and last cylinder to peak with true peak detection - eliminates a false peaks
Displays both leaned temperature below peak and peak
Battery voltage with alarm
24 Programmable alarm limits
Normalize view
DIF low to high EGT with alarm
EGTs to stable 1°F resolution
Shock cooling monitored on every cylinder
User selectable index rate
Fast response probes
Non-volatile long term memory
Records and stores data up to 30 hours
Post-flight data retrieval
Data retrieval software
Fuel Flow
Solid-state rotor fuel flow transducer
Fuel quantity in gallons, kilograms, litres, or pounds
Low fuel quantity alarm
Low fuel time alarm
GPS interface
Instantaneous fuel flow rate
Total amount of fuel consumed
Total fuel remaining
Time to empty at the current fuel flow rate
Displays % horsepower and RPM
Automatically calculates percent horsepower

However, another important decision which was necessary to make refers to the emplacement of this instrument on the aircraft. Firstly, a Turn Indicator, Slip Indicator and Bank indicator on the instructor's side of the instrument panel were removed and a fuel gauge was put into the position where the Turn and Slip Indicator were previously placed. The free space where the fuel gauge was located had become the place for the EDM-800 monitoring system (as can be seen in Figure 3) and the diameter of the instrument was 2 ¼ inch (Kříž et al, 2010).

Figure 3. EDM-800's emplacement on the instrument panel in Zlin 43 (Kříž et al, 2010)

Another important part of all monitoring system is represented by the way to download recorded and stored data to the computer and subsequently their use for monitoring and evaluation.

For this purpose a special utility program – ***EzTrends*** – is used which transfers the compressed data from the EDM instrument to the PC and later it decompresses these data. After that, the data will be plotted and shown in the form of table or graph (the user can choose displaying options). Also, the user can choose plotting all parameters at the same time or separately. Moreover, the user can transfer all data that are stored in the EDM to the PC (illustration of the EzTrends program window can be seen in Figure 4) or can transfer just the data that were recorded since the last data's transferring process. In common, EDM stores the data for 20 hours, but the length depends on the options that are chosen and installed. Furthermore, the EDM's data are downloaded to the PC through the serial port and the EzTrends software decompresses the data file and it also divides them into separate flights (Romanova, 2014).

Figure 4. Ez-Trends software screenshot [author]

Briefly, monitoring of the engine parameters plays an important role in pilot training and it helps to detect the existing problems in engine operation and to prevent potential engine malfunctions in the future.

3. MONITORING OF THE SELECTED PARAMETERS OF THE M337 ENGINE

For the purpose of this paper we will monitor these parameters of the M337 engine:

a) Exhaust Gas Temperature (EGT)

b) Cylinder Head Temperature (CHT)

EGT is a parameter that describes the temperature of the exhaust gases that exit the cylinder. This temperature depends on the power setting, altitude, and ambient air temperature and on the cylinder compression. It is also influenced by the engine mechanical conditions, such as cylinder leakage. CHT is the residual heat from combustion and therefore should be able to provide much of the same diagnostic information. The main difference between CHT and EGT is the time of response where EGT is much quicker to change and then the changes are larger in magnitude. Therefore, EGT is much more valuable tool to detect the irregularities in the whole combustion process (Miljkovic, 2014).

Furthermore, CHT is important from the cylinder head thermal load point of view. EGT is important because of thermal load on the combustion area materials. These two parameters tell us how the piston engine works, what is the fuel mixture, but at the same time it indicates any abnormality in the combustion process.

It is important to set optimal mixture, which is chosen according to the selected mode of operation and the desired output. Slightly richer mixture, slightly increases engine performance (all supplied oxygen is burned) and the fuel excess can lead to the cooling of the combustion process. On the other hand, the fuel consumption can be significantly higher than at a slightly leaner mixture.

Leaner mixture will cause a decrease in performance (because not all oxygen is burned), but the increased temperature can lead to damage to the engine itself (Hrčka, 2007), (Mikalsen et al, 2007).

The change of mixture changes also the temperature and the characteristics of combustion and, consequently, we need the indications of the Exhaust Gas Temperature - EGT. Figure 5 below shows the relationship of mixture to EGT, CHT, power output and specific fuel consumption.

The left part of Figure 5 shows the take-off power setting. The mixture is richer than at the maximum power while the cylinder head temperature is low. This condition prevents detonation and overheating of cylinders during high power operations. For maximum performance the exhaust temperature and the cylinder head temperature is below their peak. At the point where the mixture is leaner the operation is most economic. EGT is slightly below its peak and CHT is well below its peak and is lower than the point of maximum power. Therefore, at the point of peak CHT, the operation of an aircraft should be minimal because of high CHT negatively affecting cylinder life.

Therefore, the object of research is to evaluate the operation of each cylinder separately. Monitoring of EGT for each cylinder individually will help us understand the need for fuel/ air ratio for each cylinder separately (Macdonald, 2011), (Ortiz, 2013).

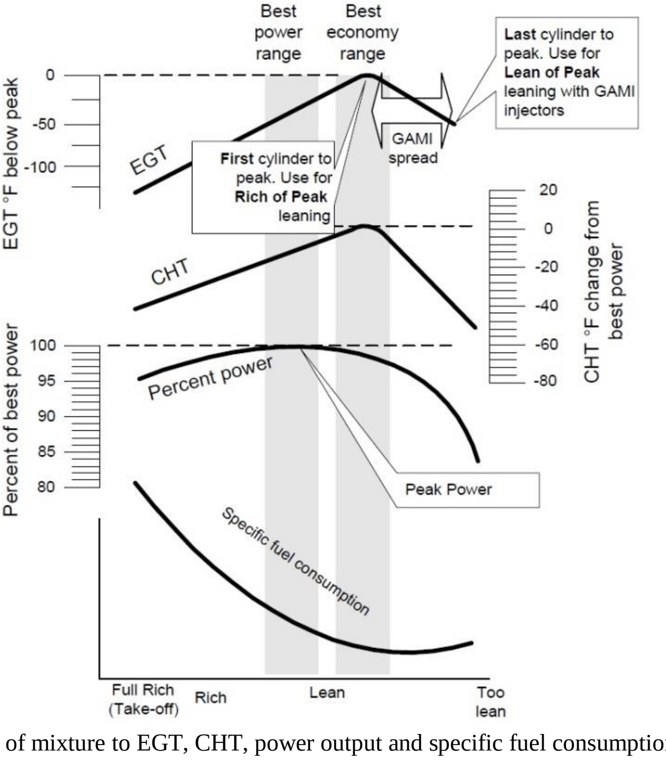


Figure 5. Relationship of mixture to EGT, CHT, power output and specific fuel consumption (Inc., 2007)

The parameters will be investigated in 3 power settings, during take-off, climb and cruise.

These modes are standardized in terms of engine speed and manifold pressure, so the results will be well comparable for certain flights or for a specific examined period.

To investigate the single power output would be insufficient because the engine power setting change also changes the thermal load.

The following table gives the engine settings with corresponding propeller RPM and manifold pressure for Zlin 43.

Table 4. Flight regimes and corresponding engine settings [author]

ZLÍN 43		
Flight regimes	**RPM**	**MAP (at)**
Take-off	2750	1,2
Max. continuous	2600	1,0
Max. cruise	2400	0,92
Economic	2300	0,84

M337 piston engine has 6 cylinders, and the aim of this monitoring will be to learn how each cylinder works separately during the selected flight regimes.

The result will help us to find out how to manage the economic operation of the engine and at the same time it also prolongs its life. The values will be monitored during both the summer and winter operation.

3.1 Analysis of the data gathered from the EDM-800 system in relation to the selected flight regimes

This subchapter describes the gathered average values of the EGT and CHT during the selected flight regimes of Zlin 43 aircraft with registrations Zlin 43 OM-KOZ and Zlin 43 OM-LOW that are used for pilot training in the Air Training and Education Centre.

Table 5 and Table 6 below illustrate the measured values of the engine during both the winter and summer operations for Zlin 43 OM-KOZ and Zlin 43 OM-LOW aircraft.

Table 5. Flight regimes and values of the EGT for Zlin 43 OM-KOZ [author]

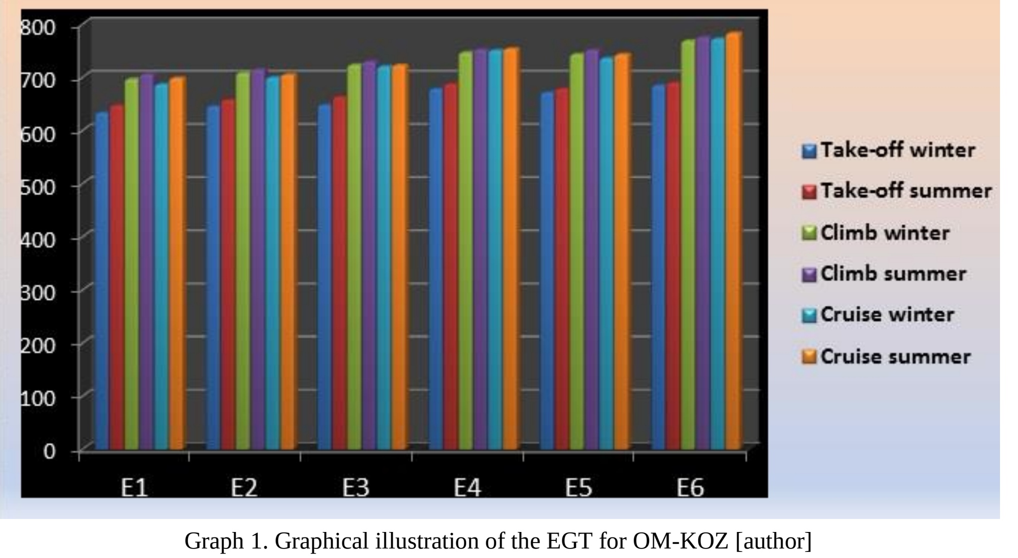
Zlin 43 OM - KOZ												
Regime	**Exhaust Gas Temperature (°C)**											
	E1		**E2**		**E3**		**E4**		**E5**		**E6**	
	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer
Take-off	633,6	647,27	645,5	657,52	647,8	663,28	678,2	687,46	671,4	678,59	685	689,73
Climb	696,7	706,26	708,3	715,07	723,3	730,04	746,5	752,8	743,2	752,01	768,4	775,74
Cruise	686,8	698,5	699,5	704,74	720,2	722,68	750,6	753,4	735,8	742,95	772,5	782,91

Table 6. Flight regimes and values of the EGT for Zlin 43 OM-LOW [author]

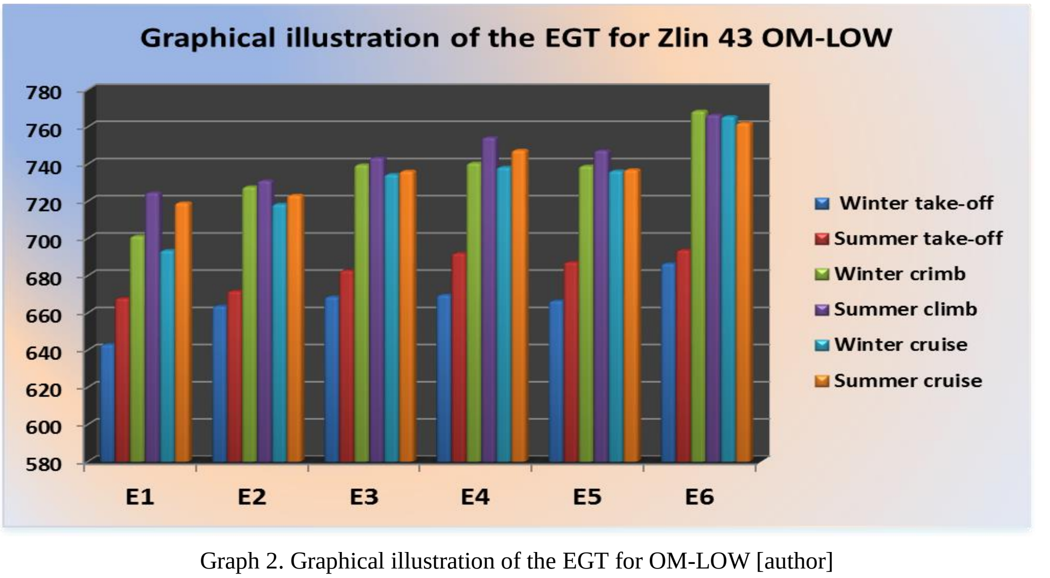
Zlin 43 OM - LOW

Regime	Exhaust Gas Temperature (°C)											
	E1		E2		E3		E4		E5		E6	
	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer
Take-off	643	667,85	663,6	671,68	668,6	682,69	669,6	692,02	666,5	687,23	686,5	693,7
Climb	701,3	724,64	727,8	731,04	739,6	743,34	740,5	754,27	738,9	747,24	768,5	766,42
Cruise	693,5	719,16	718,4	723,25	734,5	736,18	738,3	747,43	736,3	736,96	765,6	762,07

The Next graphs illustrate different measures of the Exhaust Gas Temperature during the selected flight regimes.



Graph 1. Graphical illustration of the EGT for OM-KOZ [author]



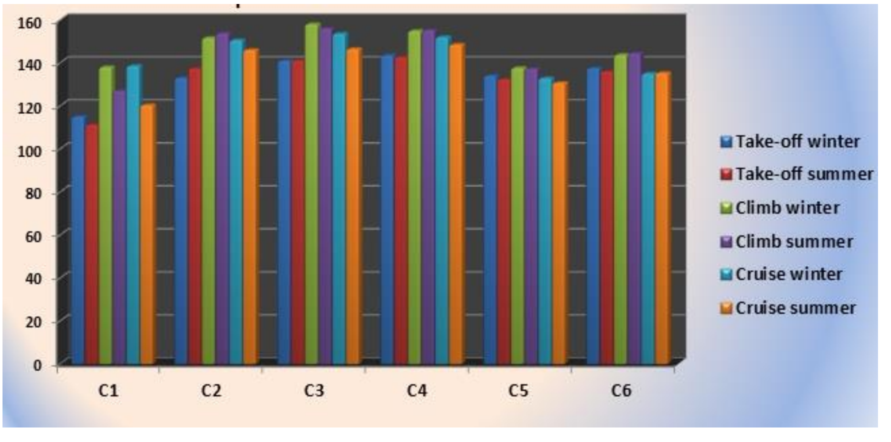
Graph 2. Graphical illustration of the EGT for OM-LOW [author]

Table 7. Flight regimes and values of the CHT for Zlin 43 OM-KOZ [author]

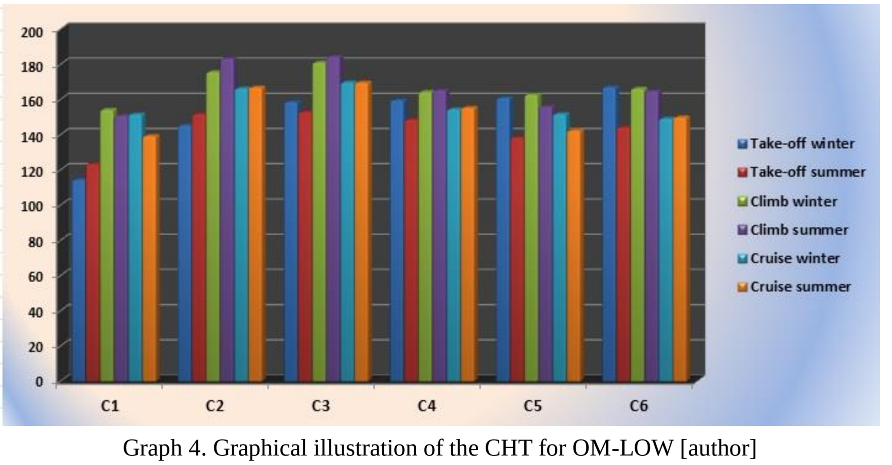
Zlin 43 OM - KOZ												
Regime	Cylinder Head Temperature (°C)											
	C1		C2		C3		C4		C5		C6	
	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer
Take-off	115,02	111,24	133,04	137,4	140,96	141,11	143,54	142,7	133,95	132,37	137,55	136,06
Climb	138,01	127,03	151,6	153,77	158,01	156,02	154,86	155,22	137,67	137,34	143,72	144,5
Cruise	138,59	120,35	150,53	145,96	153,59	146,47	151,98	148,5	132,89	130,66	135,02	135,3

Table 8. Flight regimes and values of the CHT for Zlin 43 OM-LOW [author]

OM - LOW												
	Cylinder Head Temperature (°C)											
	C1		C2		C3		C4		C5		C6	
	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer
Take-off	114,41	123,33	145,24	151,73	158,48	152,85	159,6	148,54	160,91	138,36	167,08	144,2
Climb	154,22	150,82	175,57	183,25	181,04	184,43	164,35	165,24	162,78	155,93	166,19	164,78
Cruise	151,58	139,25	166,28	166,83	169,73	169,59	154,47	155,29	151,77	142,39	149,13	149,89



Graph 3. Graphical illustration of the CHT for OM-KOZ [author]



Graph 4. Graphical illustration of the CHT for OM-LOW [author]

Briefly, based on the tables and graphs from the previous paragraph, we can summarise that in cruise regime the engine runs at the highest EGT and CHT at the same time.

These values result from the leanest mixture. On the other hand, in cruise flight regime the mixture is richer because of engine cooling and regular operation and because of this, CHT and EGT are lowest.

4. RESULTANT CONCLUSIONS

The goal of this paper was to monitor the engine parameters by analysing the data recorded by EDM-800.

The monitoring presented in this thesis contains the statistical analysis of the engine parameters for different engine working regimes and the comparison of the parameters of two different engines. The data were presented in tables and graphs.

While analysing the data, some deviations were noticed. The most common problems were:

- CHT on some cylinders was higher than on the other ones. Possible cause: the ring can be broken or there's something wrong with the cooling system and the cold air doesn't get to some cylinders.
- There is a big difference between the highest and the lowest EGT. Possible cause: injection nozzles are dirty or there's a problem with the induction system.

However, the causes mentioned above are only theoretical and further analysis is required. Briefly, the EDM-800 system also helps the aircraft maintenance at the Air training and education centre of the University of Zilina to determine and localize malfunctioning components of M337 piston engines.

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REFERENCES

[1] * * * Hrčka (2007, September 8). *Aeroweb*. Retrieved on September 27, 2014 from http://www.aeroweb.cz/clanek.asp?ID=826&kategorie=3

[2]* * * Inc., J. I. (2007). J.P. Instruments. Pilot's Guide. Retrieved on October 20, 2014, from https://www.jpinstruments.com/wp-content/uploads/2012/10/PG-EDM-800-Rev-W.pdf

[3 Mikalsen et al, A review of free-piston engine history and applications, *Applied Thermal Engineering*, Volume **27**, Issues 14-15, Pp.2345-2348, 2007.

[4] Kříž, *Implementation of the EDM-800 monitoring system.* Conference – New trends in civil aviation. Zilina, 2011.

[5] Macdonald, *Owner Assisted Aircraft Maintenance*, Alpha Zulu LLc. Eden Prairie, 160 p, 2011.

[6] Romanova, *Monitoring of M137 aicraft engine.* Bachelor thesis. Zilina, 2014.

[7] Taylor, Jane's all the world's aircraft 1980-81. London: Jane's. pp. 120-125, 1980.

[8] Tizek, *LOM Prague piston engines and propellers production*, 1992.

[9] Miljkovic, *Aircraft Piston Engine Fault Detection Based on Uniformity of Cylinder Head, Exhaust Gas and Turbochargers Temperatures*, ECNDT Conference, Prague, 2014.

[10] Ortiz et al, *Failure analysis of the engine cylinder of a training aircraft, Engineering Failure Analysis*, Volume **35**, Pp. 687-888, 2013.