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AVIATION PISTON ENGINES – FLIGHT PARAMETER ANALYSIS

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Abstract

A program and tools enabling general aviation operators in our country the exploitation of the piston engines on-condition has been developed in the Institute of Aviation. Apart from the existing and strictly supervised engine manuals tasks, the program introduces, among other things, new maintenance mandatory activities like engine parameter monitoring during cruise and climb and a way of assignation diagnostic tolerance limits for them. That has never been performed in the aviation piston engines maintenance practice.

In order to improve such analysis a flight data recorder (FDR) EDM 900 has been installed on the DA20- C1 „Katana" aircraft equipped with IO-240-B engine, which will allow elimination of the pilot's read errors and examination of the changes in the parameters during the entire flight. This will enable estimating if at a certain time of the flight a specified engine parameter is not exceeding the permissible values. Parameters from cruise have to be recorded in the similar range of the engine rpm's. The parameters are oil pressure, oil temperature, cylinder head temperature, EGT, fuel flow, outside air temperature, rpm and altitude. Lower and upper acceptable limit values should be set, in which they can be contained throughout engine life. Engineers should also observe the trend of their changes.

This article shows results of the aviation piston engine parameters analysis taken from FDR for ground runs, take-offs and cruise flight phases.

Keywords: *aviation piston engine, on-condition maintenance, engine flight parameter*

1. Introduction

A reliable aircraft engine guarantees safe realization of a flight. It concerns particularly airplanes powered by a single engine where each failure can cause a serious event. At present, there are more than 1,000 piston engines in exploitation in Poland, most of them (90%) power single engine aircraft [8].

Almost 50% of aviation occurrences contained in [7] and caused by power plants installed on those aircraft can be assigned to the piston engine itself. Most of the events are connected with powertrain and cylinder systems. There were events caused by cracked exhaust valves. In addition, carbon deposit on valves has been observed. Some occurrences were caused by different failures of the cylinders. It can be presumed that those damages were due to engines overheating, resulting from improper exploitation. Fig. 1 shows the number of the aviation events caused by piston engines in the years 2012-2015.

Improperly installed/connected oil pipes causing leaks are the main but not the only reason for the reported events connected with the engine oil system. They occurred due to maintenance imperfections. Oil system faults have a significant impact on flight safety. It needs to be mentioned that in 23 cases of the oil system malfunctions in the years 2008-2015, 16 of them resulted in aborted flights or emergency landings [7]. Fig. 2 shows the number of the aviation events caused by the piston engines oil system in the years 2012-2015.

The above descriptions presented lead to the formulation of the thesis that aircraft piston engines require changes in the current exploitation system in order to improve flight safety.

In addition to the existing maintenance and operational requirements, such a system should include new tasks like engine flight parameter monitoring which is an important part of the engine on-condition exploitation.

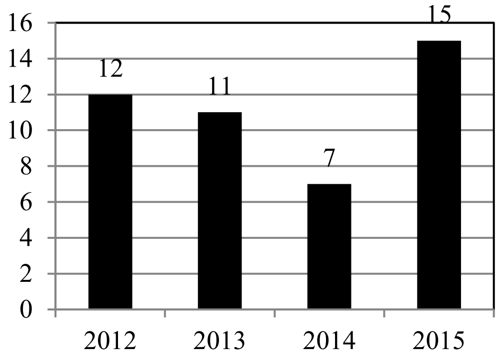

Fig.1. Number of the piston engines failures caused aviation events

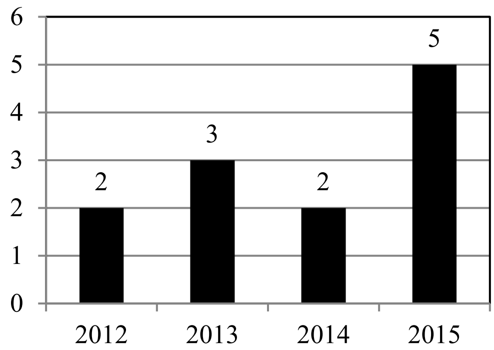

Fig. 2. Number of the piston engines oil system failures caused aviation events

2. Research method

The concept of the aviation piston engines on-condition exploitation established in the Institute of Aviation was presented in the article [1]. At that time, engine parameters were registered by the aircrew. Installation of the EDM 900 Flight Data Recorder (FDR) on the DA20-C1 aircraft powered by Continental IO-240-B engine, allowed elimination of the pilot's read errors and examination of the parameter changes during the entire flight if at a certain time the parameters do not exceed the permissible values. Fig. 3 shows instrument panel view of the DA21-C1 aircraft before a) and after b) flight data recorder EDM 900 installation.

a) *b)*

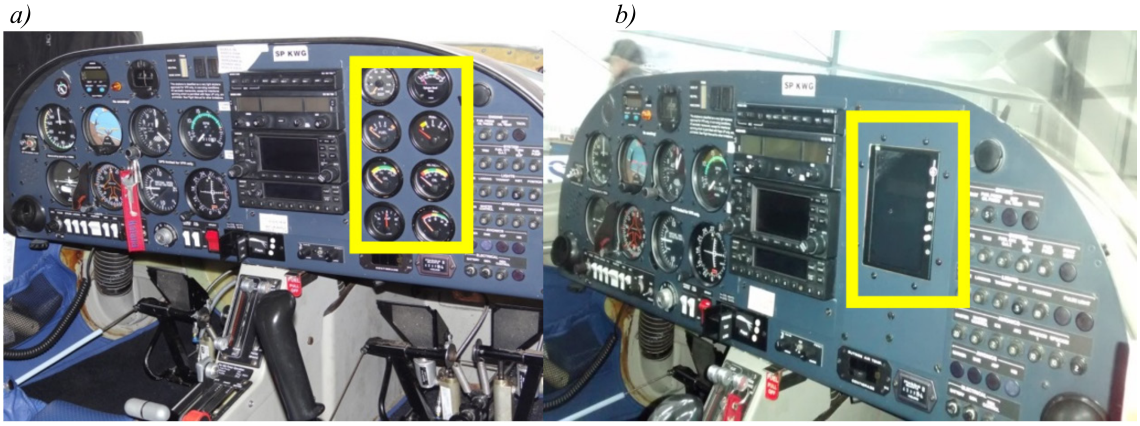

Fig. 3. Aircraft instrument panel view before a) and after b) flight data recorder EDM 900 installation

The most important part is the way the engine parameters from the flight are analysed. They have to be recorded during take-off/climb and cruise but in the same range of engine rpm's. It is important to track trends of their changes. The parameters are:

1. Oil pressure.
2. Oil temperature.
3. Cylinder head temperature.
4. EGT (Exhaust Gas Temperature).
5. Fuel flow.

They are registered on the FDR every second.

Cruise data from flights, which are taken into consideration for diagnostic purposes are accepted only when registered after one minute of the flight stabilization, at the same altitude with engine rotation speed in a range between 2100-2200 rpm.

Assignation of the engine's parameters values from take-off/climb are calculated as follows:

When the aircraft during take-off reaches a speed of 50 km/h, an average value of each engine parameter registered for 50 seconds from that point is calculated. It means that in our case it is an average of 50 measurements.

Determination of the range, in which the above parameter values should be contained. It needs to be carried out based on the data from each flight (the first 50 hours after the engine installation) and take-off/climb (the first 20 flights after engine installation), assuming their Gaussian distribution.

For each parameter, the mean value should be counted.

$$P_{ŚR}=\sum_{i=1}^{n} Pi/N, \tag{1}$$

and the standard deviation:

$$б=\sqrt{\frac{\sum_{i=1}^{n}(Pi-Pśr)^2}{N-1}}, \tag{2}$$

where:

N – number of flights,
P_i – parameter value,
$P_{ŚR}$ – mean value.

For the next overhaul, a replacement of the engine or the propeller replacement, each parameter value should be within established range, from m+3σ to m-3σ.

If any of the parameter values exceeds the limit, the cause of it has to be determined immediately.

Figure 3 shows as an example a graphical summary of the above-mentioned descriptions and calculations.

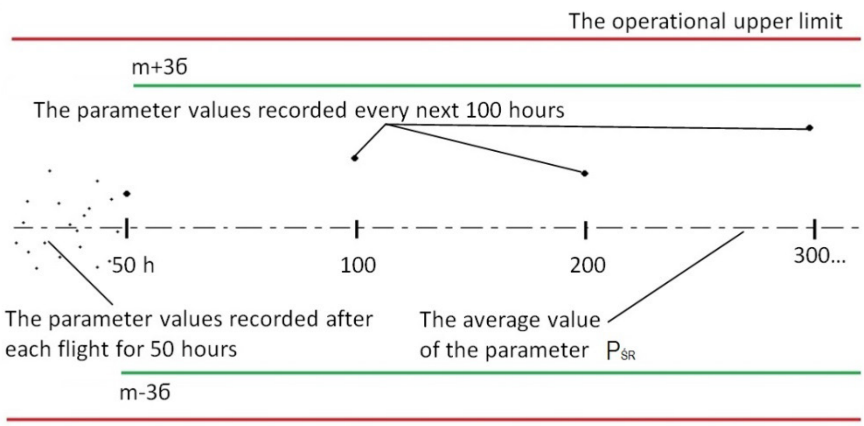

Fig. 3. Example of graphical representation of the value changes for one of the operational parameters of the engine in flight. The operational upper limit is greater than the upper diagnostic (m + 3σ) limit

3. The calculations results

Figure 4 shows picture of the engine IO-240-B parameter changes during two flights, recorded on the EDM 900 FDR installed on DA20-C1 aircraft. Upper part of the picture presents each cylinder head temperature and EGT. Lower part shows engine rpm, fuel flow, oil temperature. Remaining necessary for engine condition assessment parameters: oil pressure, fuel pressure, outside air temperature (OAT), altitude, aircraft speed are not shown on graphs.

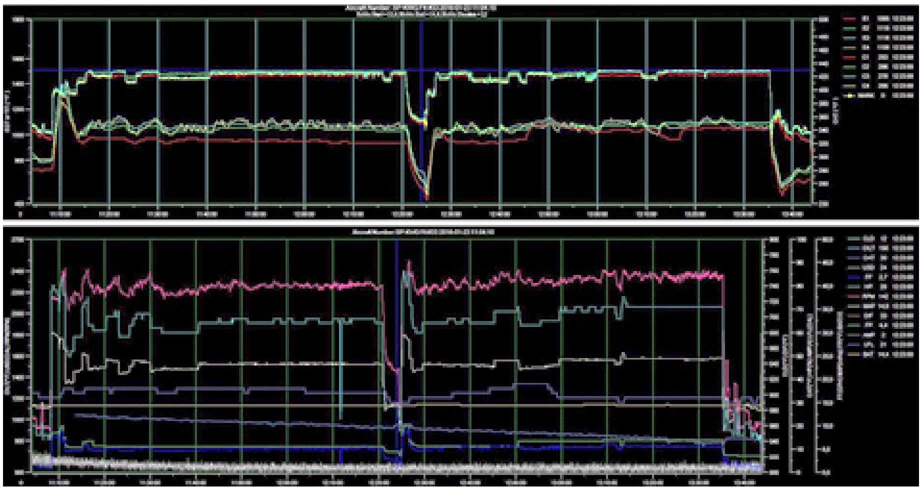

Fig. 4. Example of two flights registered on EDM 900 flight data recorder

Figure 5 shows view from the top of the IO-240-B engine installed on DA20-C1 aircraft.

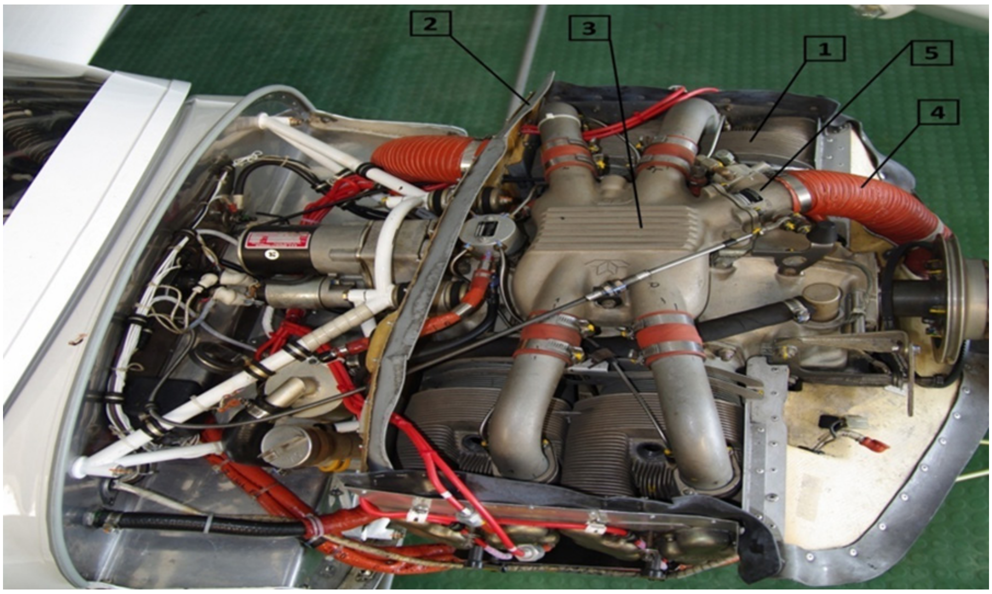

Fig. 5. IO-240-B engine seen from the top, 1 – cylinder no 4, 2 – baffles, 3 – manifold of the air supplied to the cylinders, 4 – air supply hose, 5 – throttle

The installation of the FDR besides the engine's oil and fuel parameter registration made it possible for every cylinder's head temperature as well as for EGT, measured after each exhaust valve. It is very important because the condition of the aircraft's baffles could be evaluated more precisely. They guide the cooling air around cylinder heads and barrels. In addition, other baffles channel provides cooling air into oil radiators. If the cylinder head temperature or oil temperature approaching the limit than the baffles technical condition has to be checked. When they are properly installed, troubleshooting in order to find reason high temperatures could be established.

3.1. Cruise

Figure 6 shows each cylinder head temperature during cruise phase of the flight, recorded on the EDM 900 FDR. Also, operating as well as calculated new, so-called diagnostic limits are presented.

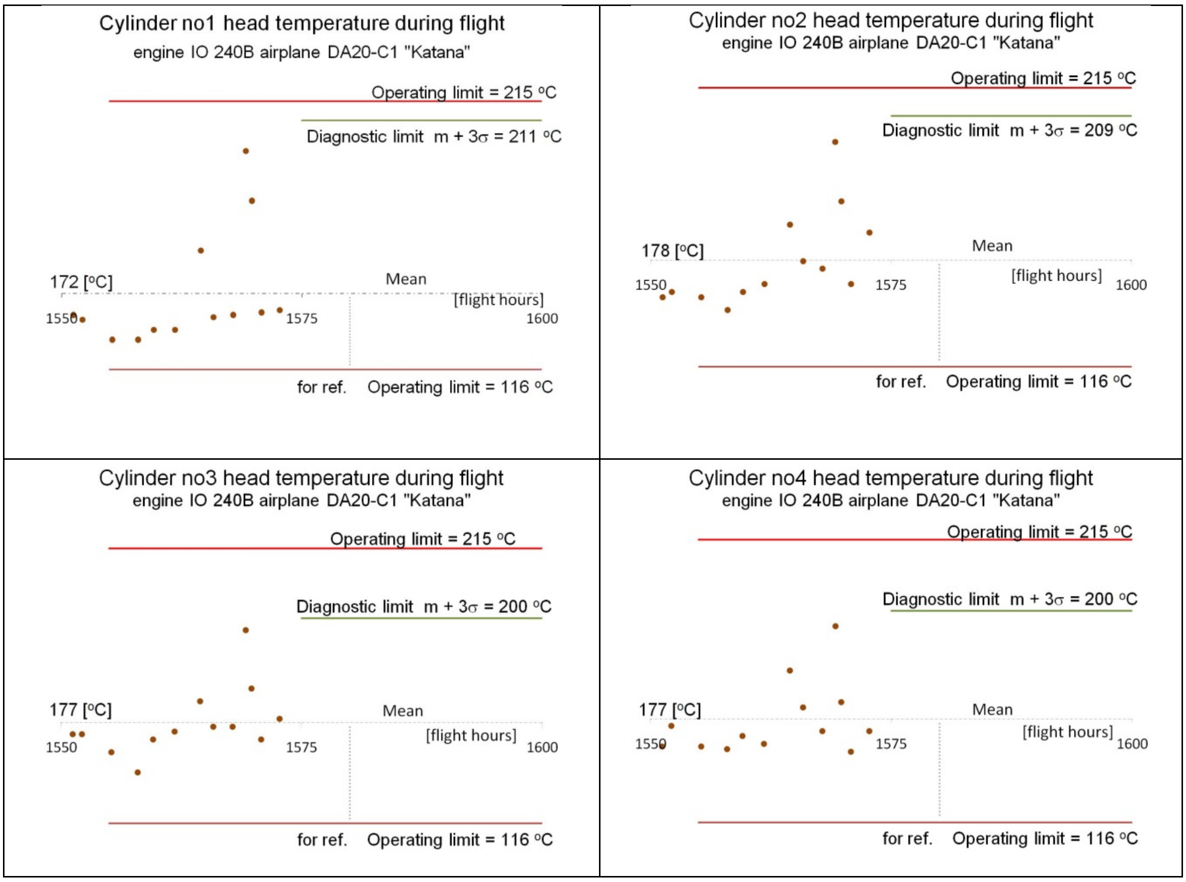

Fig. 6. Each cylinder head temperature limit during cruise of the IO-240-B engine installed on DA21-C1 aircraft

FDR has enabled precise readings of the cylinder's temperature. It has to be pointed out that diagnostic limits calculated for the cylinders 3 and 4 are significantly lower than for the cylinders 1 and 2. Such situation results from better cooling of the cylinders 3 and 4, which are closer to the engine's air inlet.

Figure 7 presents established diagnostic limit for engine oil temperature, while Fig. 8 shows engine's rpm values when its parameters were recorded.

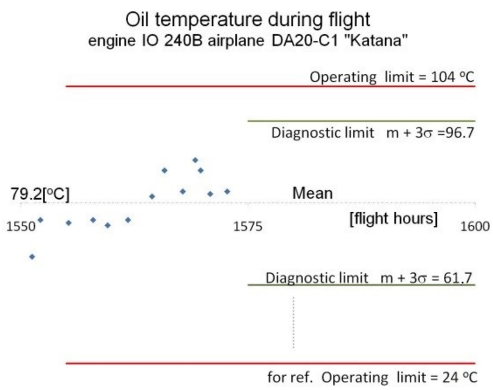

Fig. 7. Engine oil temperatures during cruise and calculated diagnostic limit

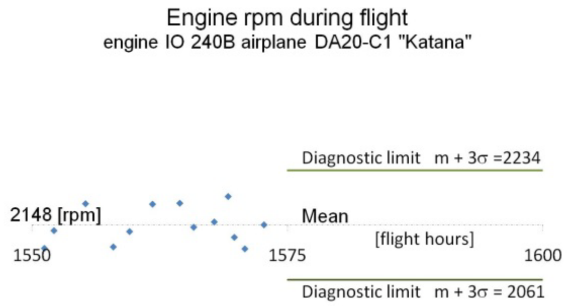

Fig. 8. Engine rpm's values during cruise when its parameters were recorded

All of the engine's new calculated diagnostic limits for its parameters are below operational restrictions included in the IO-240-B Engine Manual [5] for the cruise phase of the aircraft flight**.**

3.2. Take-off/Climb

The phase of the flight during which aircraft engine is subject to high temperature stresses is take-off/climb. Recorded from this part of the aircraft flight engine parameters are providing important diagnostic information, describing an engine condition. Knowledge of their values in the discussed here flight phase allows an engineer (computer program) to perform calculations and as a result for take-off/climb parameters, diagnostic limits establishment. Such procedure is only possible if engine's parameters are registered automatically. Fig. 9 shows each cylinder head temperature during take-off/climb, recorded on the EDM 900 FDR. Also operating as well as calculated new, diagnostic limits are presented.

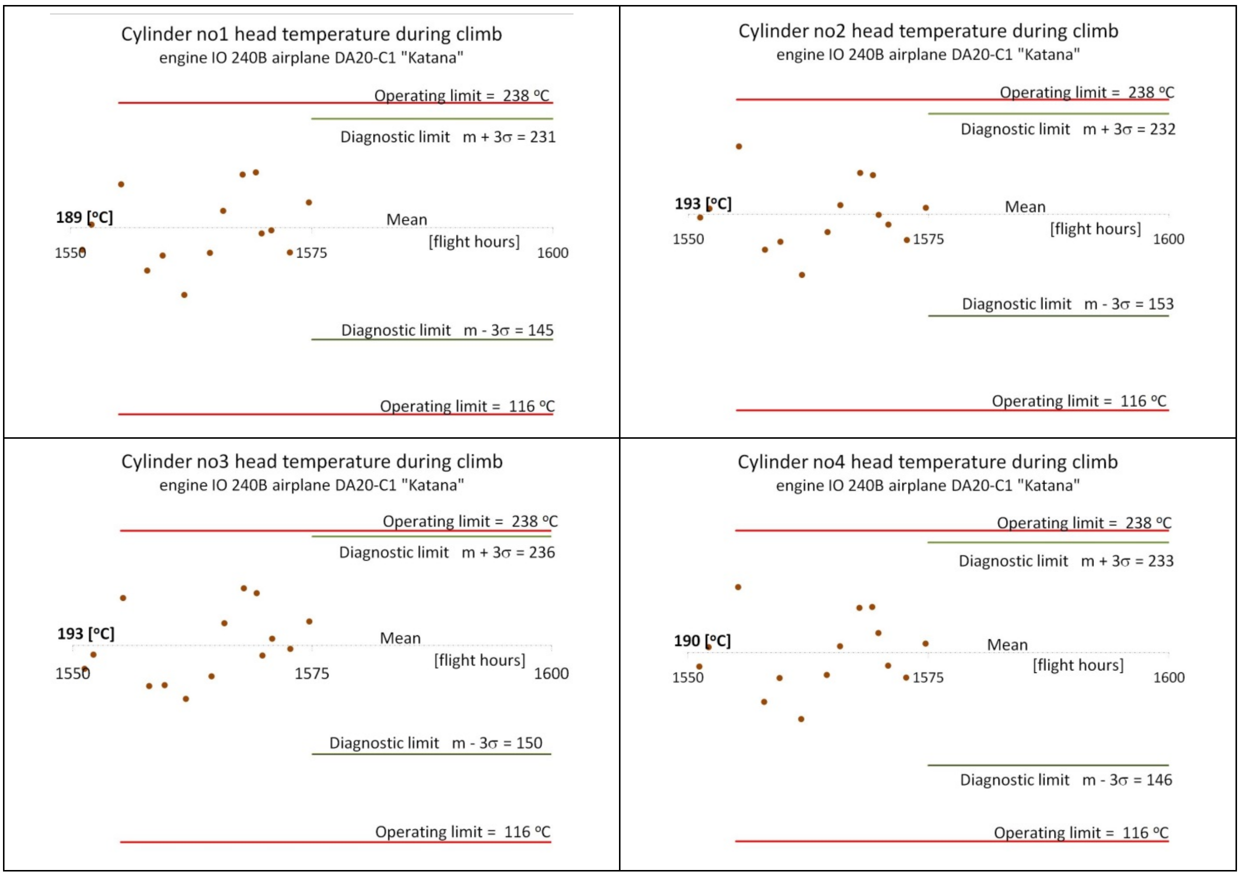

Fig. 9. Each cylinder head temperature limit during take-off/climb of the IO-240-B engine installed on DA20-C1 aircraft

Figure 10 presents engine oil temperature parameters during take-off/climb phase of the flight and calculated diagnostic as well as engine manual operational limit.

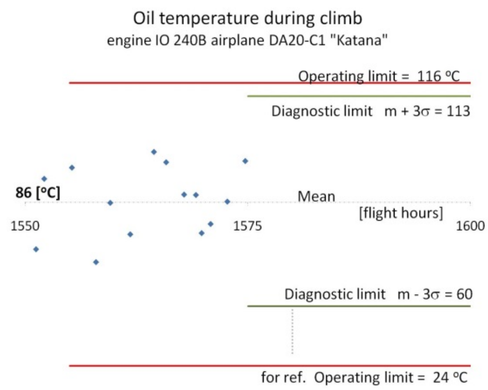

Fig. 10. Engine oil temperatures during take-off/climb and calculated diagnostic limit

Lower diagnostic limit especially for cylinder head and for engine oil temperatures are much higher than engine manual minimum limit. For engine TBO (Time Between Overhaul) extension, it is advisable to perform engine heating before flight to higher temperature values than those given in the manual.

4. Conclusions

Presented in the article measurement results are taken from only first FDR installed on the aircraft with engine "on-watch". This enabled assessment of diagnostic limits for that engine. Further continuing measurements will enable engine's parameter changes within its life.

Positive outcomes of the results for the engine analysis based on the Flight Data Recorder will enable the extension of FDR capabilities for the aircraft flight parameters, which will lead to the introduction of an objective flight control and thus will improve flight safety. A registered engine as well as flight management parameters analysis will make possible accurate detection of the failure causes. Also, immediate information about any parameter exceedance over diagnostic or aircraft/engine manual limits will be provided.

For every single engine, individual diagnostic limits have to be established.

5. Plan for the future

Engines vibration is an important parameter indicating possible imbalance of the various powertrain elements as well as irregular combustion processes. Up to now, vibration monitoring system has not been adopted on aviation piston engines. There are scheduled engine tests on the newly opened in the Institute of Aviation test-cell in order to find the best place on the engine for vibration sensor/s installation. Promising results of such research will allow installation of the vibration monitoring system on the exploited engine.

Acknowledgement

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