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Influence of oil service life on selected performance parameters of an aircraft piston engine

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This article presents an analysis of the influence of oil service life on the performance parameters of an aircraft piston engine lubrication system used in an ultralight aircraft. The ageing of oil between oil changes causes a change in its parameters (such as density, viscosity...). These parameters have a strong influence on the level of protection of the lubricated components. Currently, in aircraft, oil changes are carried out according to a time schedule – oil is changed every fixed period (residual life) regardless of its actual condition. The task of this article is to test the possibility of an indirect assessment of oil condition based on analysis of changes in selected parameters of engine lubrication system operation during normal operation. The oil warm-up speed during the pre-start procedure and the dependence of oil pressure on engine speed were assumed for the analysis. The study was conducted on an ultralight rotorcraft during normal operation. Selected first daily flights directly after oil change, and after 17, 32, 50 and 66 hours of operation were analysed. It was shown that the warm-up rate changes in the samples analyzed, but that this change may also be due to factors other than oil operating time. In the case of the oil pressure vs. speed characteristics, different characteristics were shown for different operating time, but no specific dependencies were found.

Key words: *remaining useful life, engine oil, gyrocopter, gyroplane, exploitation monitoring*

1. Introduction

From the first years of the XXI century, the market of ultralight aircraft mainly gyroplanes, is growing rapidly. On the base of the registry conducted by the Polish Aviation Authority, the number of registered gyroplanes raised from 0 in 2008 [17] up to 105 pcs. in 2022 [15].

These aircraft cover mostly the needs of hobbyists but, since 2013 (the year of the law change in Poland [1]) more and more jobs can be done using this type of aircraft. It is widely used as a platform for power lines or gas pipes scanning. In geodesy [4], it is used to prepare maps and photographs of longitudinal objects. In the agro industry it is used for both biological and chemical crops and forests protection. It is used in the field of surveillance and professional photography. For the last few years, it can be also seen in agro works, in monitoring the state of agrocenosis [5].

According to that, the market for maintenance has grown as well. It can be seen that not all of the owners and operators are careful enough with their aircraft. As safety is the biggest value in aviation, all – the manufacturers, operators, mechanics, owners and pilots are looking for the way how to make it safer. That is why the last decade was the decade of "electronic transformation" in the ultralight aircraft market. Most of the manufacturers moved away from analog avionics in favor of electronic ones. It opened new possibilities for system development. We can now see all kinds of different devices that could be connected to onboard avionics. It is to help the pilot or to modify the aircraft to suit the owner needs. One of these, which can improve safety the most, is a Flight Data Recorder that collects all the data during the flight. It collects air data (e.g. Airspeed) and engine data (e.g. rpm, fuel consumption).

As in modern aircraft Flight Data Recorders are fitted as standard a lot of analysis can be done after or even during every flight. What is common in airlines using QAR [10, 22] (quick access recorder) can be now done in every small aircraft.

It is known from the automotive market [6, 9, 14] that the analysis of the oil degradation based on the record of the engine parameters can be done. Such a system of Remaining Useful Life of engine oil prediction is being onboard of many modern vehicles. The authors of this article think that it is the right time to introduce such a system in ultralight aircraft.

Till now, all of the oil changes were conducted according to total flight/operation time in ultralight aircraft. Most commonly every 100 hours [2, 18]. Such a condition is not optimal in two ways. For the user, it would be best to replace the oil just before the moment that it lubricates the engine not enough, not to lower the expected life time of the engine [8, 21]. It is expected that this point is sometimes earlier than 100 hours – if the pilot uses the aircraft extensively or later if the aircraft is being used gently, e.g. only on long flights with good weather.

The topic of the operation of objects based on condition analysis is widely described in the scientific literature [7, 11, 19, 20, 23]. It has been shown that in the case of internal combustion engines, it is possible to diagnose their condition on the basis of selected parameters of operation, and one of the most important factors determining the operating condition of the engine is the condition of the lubricating oil. These studies have shown a significant link between operating conditions and oil consumption rate. This allows prediction of oil condition degradation in on-board diagnostic systems and, based on this, suggests to the user the moment of oil change. This research work was carried out mainly for engines that powered vehicles or stationary engines. Operating conditions for aircraft engines are significantly different, which can significantly affect these correlations.

This article is the first step in developing a method for diagnosing oil condition based on aircraft operating conditions. It will allow assessment of oil condition and prediction its degradation. Authors think that it would be best for the owner of the aircraft and for the environment to replace oil just in the time when it is needed [3, 16].

2. Materials and methods

2.1. Research object

The research object is a Tercel Carbon gyroplane Fig. 1 manufactured by a Polish manufacturer Aviation Artur Trendak. It is an ultralight aircraft made for leisure, professional and training flights. It is a developed version of the Tercel gyrocopter, produced continuously since 2012. The biggest changes compared to the previous model are the change of the supplier of the engine block and the change to a full carbon fiber composite body instead of glass fiber composite.

Fig. 1. Tercel Carbon at flight [12]

Its empty weight is 332 kg, and the MTOW has not changed and is 560 kg. The rest of its performance and technical data is shown in Table 1.

Table 1. Tercel Carbon performance and technical data [2]

Geometric data		
Rotor diameter	8.6	m
Rotor surface	58.06	m^2
Rotor blade chord	0.20	m
Overall length (without rotor)	5.04	m
Fuselage width	2.35	m
Track of wheels	2.20	m
Cockpit width	1.36	m
Overall width	2.35	m
Overall height	2.87	m
Wheel diameter	0.35	m
Weight data		
MTOW	560	kg
Empty weight	332	kg
Load capacity	228	kg
Data of the power unit		
Engine type	AAT 912 RSTi	
Engine power (at 5800 rpm)	140	HP
Reducer ratio	1:2.43	
Propeller	KASPAR AERO 2/3 LT	
Propeller diameter	1.72	m
Capacity of fuel tanks	80	l

2.2. Scope of research

The scope of the research was to analyze the oil temperature and oil pressure records and check if there is any dependence on the total flight time of the gyroplane after the oil change. It was assumed that changes in temperature rise time or differences in the relation between oil temperature and engine rpm could be noticed. The data was collected by the Flight Data Recorder developed by a Polish manufacturer Auto & Aero Technologies Sp. z o.o. It collects 30 different parameters every tenth of a second. The parameters most important for this research are shown in Fig. 2.

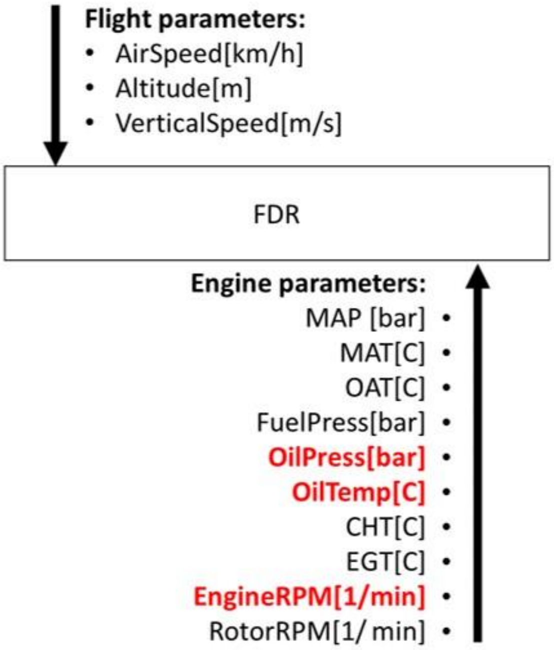

Fig. 2. Parameters collected by Flight Data Recorder

2.3. Methodology

The results were obtained by analyzing data collected from gyroplane's FDR. Data from the time between oil changes was chosen – from 400 to 500 hoobs time (a measure of the total aircraft operation time). The last oil change was done after 400 hours. As a representation for further comparison 5 flights were chosen Table 2.

Table 2. Flights chosen for analysis

	Hoobs time at record start	Duration of operation/flight
1.	405 h 3 min	23 min 25 s
2.	422 h 13 min	19 min 16 s
3.	438 h 34 min	19 min 5 s
4.	455 h 56 min	15 min 28 s
5.	471 h 25 min	10 min 22 s

To determine the changes in the oil parameters, a statistical analysis was performed. The analysis was divided into two parts. The first part was to research in the field of oil temperature rise time. The second part was to research the dependencies between engine rpm and oil pressure. Figure 3 shows the course of these parameters.

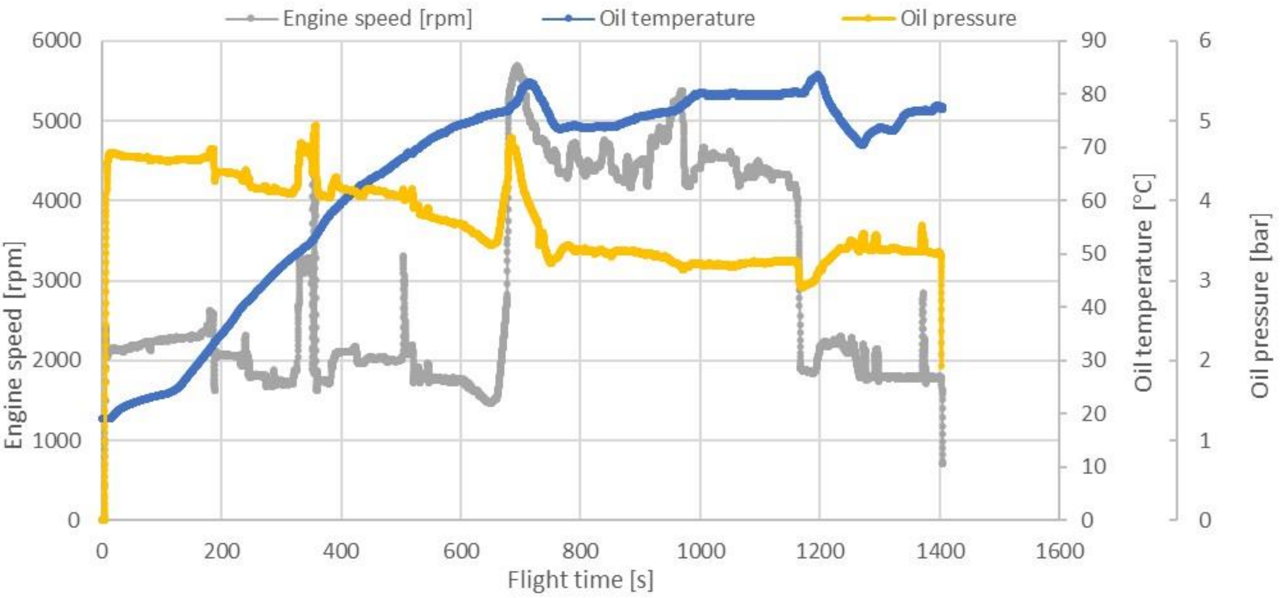

Fig. 3. Course of the parameters from flights at 405.1 hoobs time

3. Analysis of results

3.1. Analysis of oil temperature rise time

The first results were obtained in the scope of oil temperature time rise. Figure 4 shows the oil temperature change during each flight. It can be seen that the starting point depends on the initial temperature – in this case, it is the outside temperature (this was confirmed using another independent sensor – the intake temperature). The slope of the temperature rise up to 60°C can be recognized as similar in every case. Then there is a significant rise in temperature due to the maximum engine rpm achieved at takeoff. Then the temperature decreases and stays at the same average level for the whole flight.

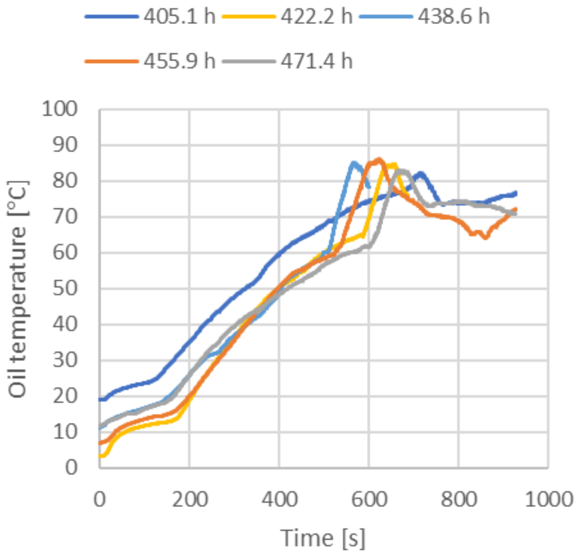

Fig. 4. Oil temperature recorded during every of 5 chosen flights

In the chosen 5 flights oil temperature rise time was measured. Starting from 25°C up to 50°C (minimal temperature needed for operation [2]) – Fig. 5. It can be seen that there are no significant differences between lines in the graph. Every line in the graph starts at 25°C. No characteristic changes with rising hoobs time could be observed. The average temp rise is between 0.112°C/s up to 0.152°C/s.

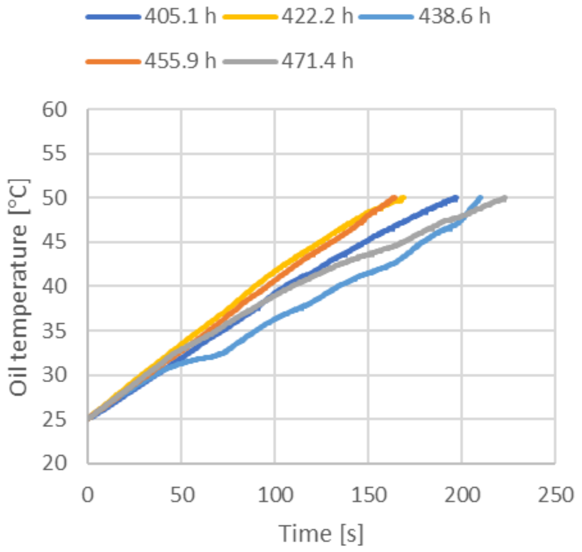

Fig. 5. Oil temperature recorded during every of 5 chosen flights. Rise of oil temperature from 25°C to 50°C

Then the rise time at each flight was shown in the graph Fig. 6. It appears that no significant dependencies could be observed in this field.

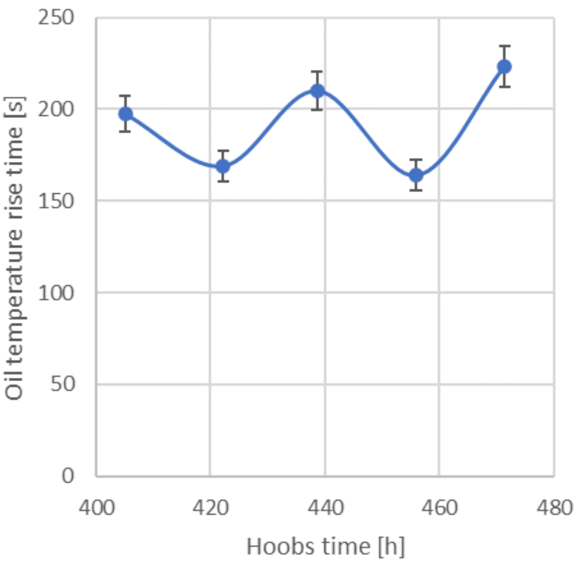

Fig. 6. Oil temperature rise time from 25°C to 50°C

3.2. Analysis of oil pressure record

Many analysis of oil pressure has been performed Fig. 7–9. No dependencies were found when comparing the full record of oil pressure during every flight. Comparing the oil pressures in the state of the rising engine rpm gave no results. This is due to the fact that the distribution of this correlation is heavily affected by the difference in flight parameters (the way the pilot performs the flight). The type and speed of maneuvers significantly affect the dynamics of changes in speed and oil pressure. Thus, it is impossible to draw conclusions from these distributions.

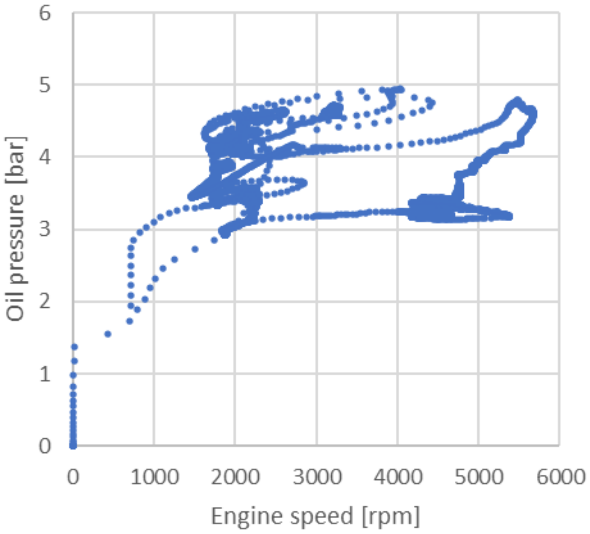

Fig. 7. Oil pressure as a function of engine speed (at 405.1 h)

Therefore, only selected operating points corresponding to steady-state flight and engine operation were analyzed. Figure 10 shows the analysis of the oil pressure in a steady state at about 4300 rpm engine set. With slight variations in engine rpm (±1%) chosen from every flight in the way that it was during a steady flight, not during takeoff, landing, or hard maneuvering. The achieved oil pressures are shown in figure 10. Each record in the graph shows the achieved pressure for a steady engine rpm. Steady states chosen from each flight vary between each other by no more than 10%. There is no upward or downward trend in relation to increasing hoobs time. For 405.1 h hoobs time, the achieved pressure was 3.21 bar at 4419 rpm, then there was 3.52 bar at 4301 rpm and then there was a drop to 3.46 bar at 4195 rpm. After that, there is a drop at 455.9 hoobs time for 3.01 at 4144 rpm, and rise again to 3.19 bar at 4528 rpm after 471.4 h hoobs time. Due to that, no relations could be found in this case.

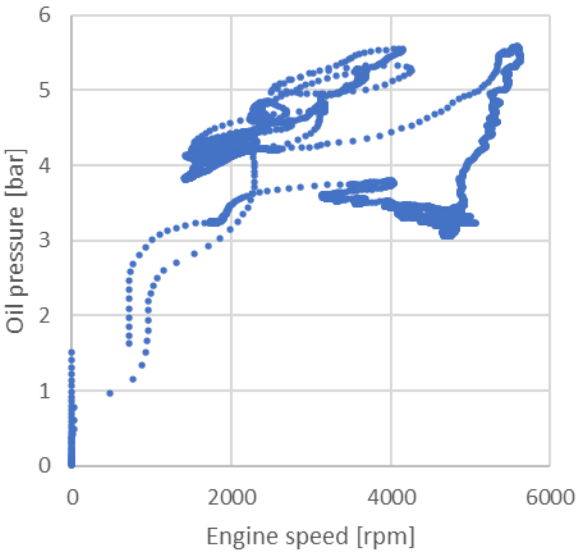

Fig. 8. Oil pressure as a function of engine speed. At 438.6 h

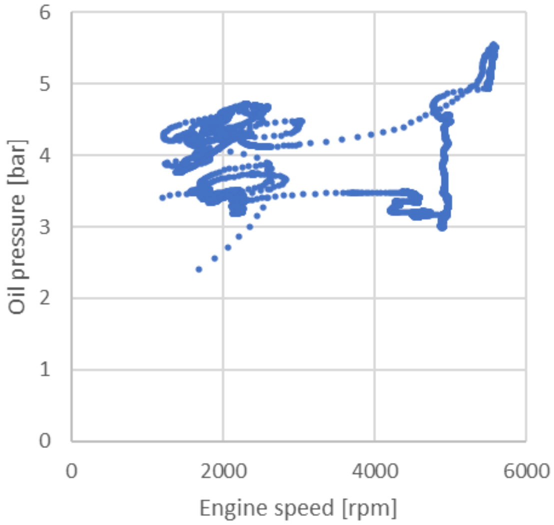

Fig. 9. Oil pressure as a function of engine speed. At 471.4 h

Then another approach was taken. Maximum oil pressure during takeoff at maximum reached rpm was analyzed in Fig. 11. In this case, some dependence could be noticed. Achieved maximum oil pressure during every takeoff raised up to about 5.5 bar. However, in order to recognize this relationship as appropriate, the same analysis should be performed for another aircraft in a similar range of total flight time. The maximum oil pressure during takeoff is a single point in a record, and it should not be taken as a proof for further inference.

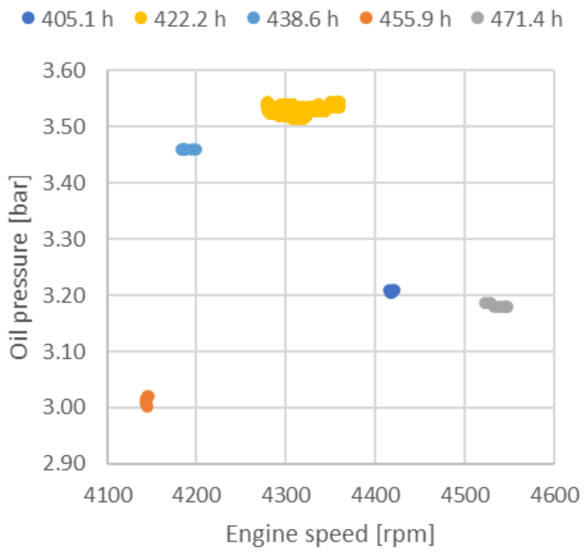

Fig. 10. Oil pressure in a steady state at about 4300 engine rpm set

4. Conclusions

No significant dependencies in the field of this research were found.

1. It is assumed that in the analysis of the oil temperature time rise, outside temperature has a significant impact. Comparing the time rise without taking it in consideration can not give results that could lead to conclusions in the field of oil degeneration.
2. The research in the field of oil pressure shown that the dependence between engine rpm and oil pressure is not changing in any particular way with rising hoobs time. This factor can not be then taken to give any conclusions about oil degeneration as well.
3. In the future, it is planned to conduct research which will take into consideration not only the recorded data but also data obtained during laboratory oil examination [13].
4. The changes in the maximum oil pressure achieved during takeoff have to be checked using records from other aircraft with similar hoobs time.

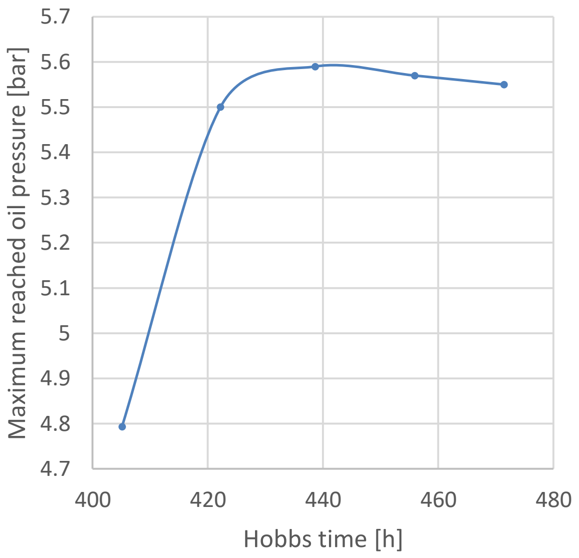

Fig. 11. Maximum oil pressure reached in every chosen flight

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Nomenclature

CHT	cylinder heat temperature
EGT	exhaust gas temperature
FDR	flight data recorder
MAP	manifold air pressure
MAT	manifold air temperature
MTOW	maximum takeoff weight
OAT	outside air temperature
QAR	quick access recorder

Bibliography

[1] Announcement of the Minister of Infrastructure of July 3, 2019 on the announcement of the consolidated text of the Regulation of the Minister of Transport, Construction and Maritime Economy on the exclusion of the application of certain provisions of the Aviation Law to certain types of aircraft and the determination of the conditions and requirements for the use of these aircraft. (Dz.U. 2019 poz. 1497).

[2] AVIATION ARTUR TRENDAK "Tercel Carbon RSTi Aircraft Maintenance Manual" Tercel-C-AMM-001-EN Edition 1, 28 Oct. 2020.

[3] Balicki W. Przetwarzanie informacji zapisanych w rejestratorze eksploatacyjnym dla celów diagnozowania stanu lotniczego silnika turbinowego, Transactions of the Institute of Aviation. 2011;213:235-244.

[4] Bareth G, Waldhoff G. 2.01 – GIS for mapping vegetation, Comprehensive Geographic Information Systems. 2018:1-27. https://doi.org/10.1016/B978-0-12-409548-9.09636-6

[5] Bzowska-Bakalarz M, Bieganowski A, Bereś P, Dammer KH, Ostroga K, Siekaniec Ł et al. Monitoring the state of agrocenosis with the use of remote-sensing gyro system. IX International Scientific Symposium "Farm machinery and prcesses managment in sustainable agriculture". 2017:64-69. Lublin 22-24.11.2017. https://doi.org/10.24326/fmpmsa.2017.12

[6] Czarnigowski JA, Rękas D, Ścisłowski K, Trendak M, Skiba K. Analysis of operating parameters of the aircraft piston engine in real operating conditions. Combustion Engines. 2021;187(4):83-89. https://doi.org/10.19206/CE-141890

[7] Gajewski J, Vališ D. The determination of combustion engine condition and reliability using oil analysis by MLP and RBF neural networks, Tribol Int. 2017;115:557-572. https://doi.org/10.1016/j.triboint.2017.06.032.

[8] Gołębiowski W, Wolak A, Zając G. Definition of oil change intervals based on the analysis of selected physicochemical

properties of used engine oils. Combustion Engines. 2018;172(1):44-50. https://doi.org/10.19206/CE-2018-105
[9] Jun HB, Kiritsis D, Gambera M, Xirouchakis P. Predictive algorithm to determine the suitable time to change automotive engine oil. Comput Ind Eng. 2006;51(4):671-683. https://doi.org/10.1016/j.cie.2006.06.017
[10] Lewitowicz J. Podstawy eksploatacji statków powietrznych, tom 4. Badania eksploatacyjne statków powietrznych. Wydawnictwo Instytutu Technicznego Wojsk Lotniczych. Warszawa 2008.
[11] Macián V, Tormos B, Olmeda P, Montoro L. Analytical approach to wear rate determination for internal combustion engine condition monitoring based on oil analysis. Tribol Int. 2003;36(10):771-776. https://doi.org/10.1016/S0301-679X(03)00060-4.
[12] Picture of Tercel Carbon provided on demand by Aviation Artur Trendak company.
[13] Piec P. Diagnostics of the wear intensity of engine oil during operation. Tribology. 2012;6:139-145.
[14] Raposo H, Farinha J, Fonseca I, Ferreira L. Condition monitoring with prediction based on diesel engine oil analysis: a case study for urban buses. Actuators. 2019;8(1):14. https://doi.org/10.3390/act8010014
[15] Registry of ultralight gyrocopters. Civil Aviation Authority of the Republic of Poland (accessed 08.04.2022).
[16] Rostek E, Babiak M, Wróblewski E. The influence of oil pressure in the engine lubrication system on friction losses. Procedia Engineer. 2017;192:771-776. https://doi.org/10.1016/j.proeng.2017.06.133
[17] Szczepanik T. Analysis of the state of the gyroplane world market. Transactions of the Institute of Aviation 2016;244(3): 227-238.
[18] Szczepanik T, Łusiak T. The maintenance gyroplanes as aircraft. Transactions of the Institute of Aviation. 2015; 241(4):87-95. https://doi.org/10.5604/05096669.1202197
[19] Wang W. A prognosis model for wear prediction based on oil-based monitoring. J Oper Res Soc. 2007;58(7):887-893. https://doi.org/10.1057/palgrave.jors.2602185
[20] Wang W, Zhang W. A model to predict the residual life of aircraft engines based upon oil analysis data. Nav Res Log. 2005;52:276-284. https://doi.org/10.1002/nav.20072
[21] Wolak A, Zając G, Żółty M. Changes of properties of engine oils diluted with diesel oil under real operating conditions. Combustion Engines. 2018;173(2):34-40. https://doi.org/10.19206/CE-2018-206
[22] Zhang C, Wang N. Aero-engine condition monitoring based on support vector machine. Physcs Proc. 2012;24(B):1546-1552. https://doi.org/10.1016/j.phpro.2012.02.228
[23] Zhu X, Zhong C, Zhe J. Lubricating oil conditioning sensors for online machine health monitoring – a review. Tribol Int. 2017;109:473-484. https://doi.org/10.1016/j.triboint.2017.01.015

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