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A MODEL FOR THE MAINTENANCE OF OLD AIRCRAFT

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Abstract. This paper presents an approach to the development of condition-based maintenance of aircraft to improve aircraft maintenance in the limits and conditions of small countries and in accordance with global technological achievements. For the aircraft that were under a limited lifespan maintenance concept, a new condition-based maintenance model is developed. This model applies a technical diagnostic method that brought us to decreasing numbers of failures in the ageing period of those technical systems and at the same time decreases the time when it is out of use and lowers maintenance expenses. An analysis based on this model showed its applicability, preservation of operational readiness, and potential for decreasing the cost of aircraft maintenance.

Keywords: maintenance, aircraft, resources, methodology, reliability.

1. Introduction

Maintenance of planes and helicopters was conducted (and still is) according to the working hours of an aircraft. Upon the expiration of the proposed working hours of a subsystem, the manufacturer recommends its overhaul and it is send to aviation factories for overhaul (Šabić 2009).

Introducing the concept of condition-based maintenance is not possible without choosing the optimal model of aircraft maintenance in the conditions of small countries.

Aircraft in the Army of Montenegro are in the third period of their life cycles. Concerning the maintenance of ageing aircrafts, there is a new trend in the world, extension of their life cycles (PLAN… 2002).

Through these procedures of extending the life cycle of an aircraft the price of their operational usage is decreased without decreasing operational readiness and flight safety (Bergaglio, Tortarolo 2000; Boller *et al.* 2000).

A maintenance model based on technical diagnostics, computer assistance, and an integrated maintenance informational system enables preservation of effectiveness, cost saving, rationalisation of maintenance tasks, and easy adoption of maintenance for modern and technically more complex aircraft in the future.

The development of a condition-based maintenance model represents a complex and insufficiently researched field in small countries because of the limited conditions.

The main goals of developing of new model for aircraft that were under a limited lifespan maintenance model are to decrease downtime, increase readiness, and lower maintenance expenses.

This paper presents an approach for the development of condition-based maintenance of aircraft to improve aircraft maintenance in the limits and conditions of small countries.

2. Presentation of new model

The new model has three branches:

– the first branch represents methodology analysis defining technical diagnostics for aircraft maintenance,

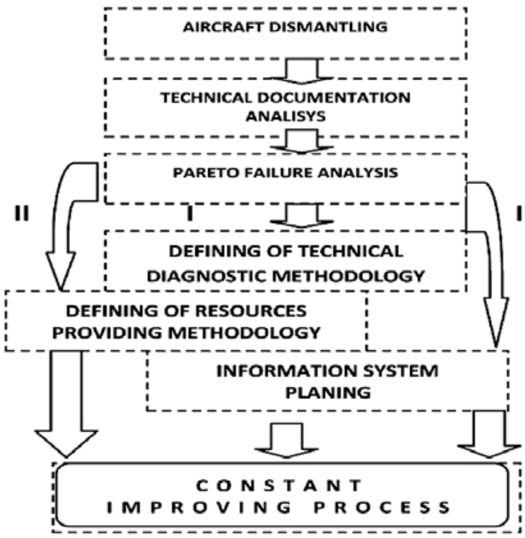

Fig. 1. Diagram of basic condition-based maintenance model

– the second branch represents methodology for providing resources for aircraft maintenance,

– the third branch represents the informational system for aircraft maintenance (Fig. 1).

2.1. Technical diagnostic methodology

The first branch represents an analysis of the systems for which there is no methodology of applied technical diagnostics (marked with I in Fig. 1). Separation is conducted on the criteria of earlier existence of the use of the method of technical diagnostics on aircraft critical systems as part of defined maintenance.

Detailed application of endoscopic and vibration methods, diagnostics of fuel and lubrication, and non-destructive diagnostic method according to disciplined methodology is suggested.

This procedure allows systematic searching of the system and covers all unknown to be accomplished. Depending on the construction and complexity of the aircraft, there are five main diagnostic methods in use.

Application of endoscopic diagnostics enables tracking changes that occur within the apparatuses of aircraft and those that are the cause of change in the parameters of the apparatuses (Fig. 2). All these unwanted occurrences can be noticed and recorded without dismantling the device (Karadžić, Bulatović 2010).

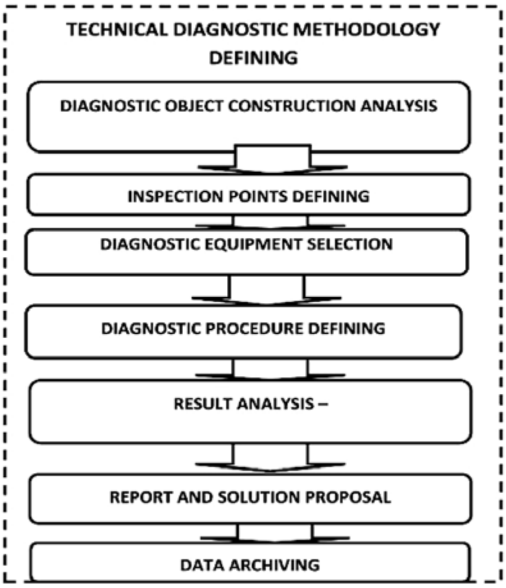

Fig. 2. "I" branch diagram

Application of vibration diagnostics can show the condition of air systems and point out the early stage of failure. Spectral analysis of motor and hydraulic lubrication oil can give us content and type of metal particles, which enables us to see the real condition of movable parts of an apparatus (RCM… 2001).

Depending on the percentage and content of metal particles, it is possible to figure out whether some movable parts are wearing out and what the quality of their lubrication is. With spectral analysis of aircraft fuel we can notice changes in the physical and chemical characteristics of fuel that can have a negative impact on functionality, especially on engine, power and throttle, in other words the combat readiness of an aircraft (Van Dijk, De Jonge 1975).

With application of these diagnostic non-destructive methods of analysis, it is possible to detect corrosion and cracks as well as changes in frame joints on the front part of the fuselage, the tail cone, etc. (Fig. 3) (Nechval *et al.* 2004).

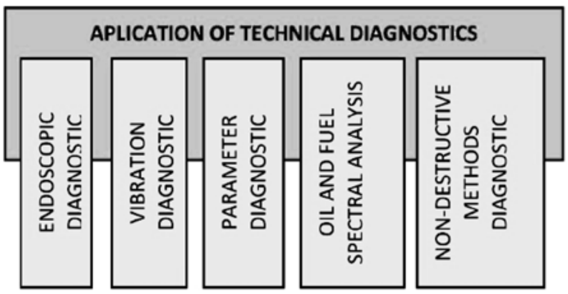

Fig. 3. Main diagnostic methods in the condition-based maintenance concept

For application of diagnostics, it is necessary to have knowledge about the construction of the object. After detailed introduction and analyses of object construction, the inspection points that will be diagnosed must be defined.

The choice of diagnostic equipment depends on the inspection points chosen, the way the inspection openings are constructed, the conditions in which the inspection will be performed, etc.

Diagnostic procedures are defined after defining inspection points and selecting accessible holes and diagnostic equipment.

Analysis of acceptable damage is one of the most important phases of diagnostics in order to decide whether to continue exploiting the object. To evaluate the acceptability of damages, comparison with standard (acceptable) damages on corresponding objects is used most often.

A report with a proposal for a solution is created on the basis of reviewed data and analysis of registered damages.

2.2. Methodology defining provision of resources

The second branch works on detailed methodology for providing resources (Fig. 4). The starting point on these systems is taken from maintenance already used, so in the analysis it is possible to rely on the experience of operators. There is a big problem in personnel, material, and time resources that must be used for analysis. That is the reason why there is no detailed analysis of this big group of systems. Because of that, selection based on safety criteria is made. In brief, it is used on groups of systems that are recognised as weak spots based on Pareto analysis (Petković, Karadžić 2010).

The methodology of extending resources consists of the following phases:

1. Analysis of aircraft documentation,
2. Determination of technical condition of aircraft,
3. Analysis of technical condition of aircraft and proposal concerning scope of work,
4. Performance of condition-based maintenance technology on aircraft,
5. Performance of condition-based maintenance technology on engine,
6. Technical diagnostic method application program,
7. Final tests on the ground program,
8. Verification program.

The application methodology of the maintenance procedure according to the condition of the aircraft engines is as follows.

1. The starting element for assessment of the possible application of engine condition-based maintenance is *comparison of construction and comparative analysis* of existing diagnostic equipment and applied maintenance procedures on similar engines (RD-33, PW1120 and F-404) (Siladić 2007).

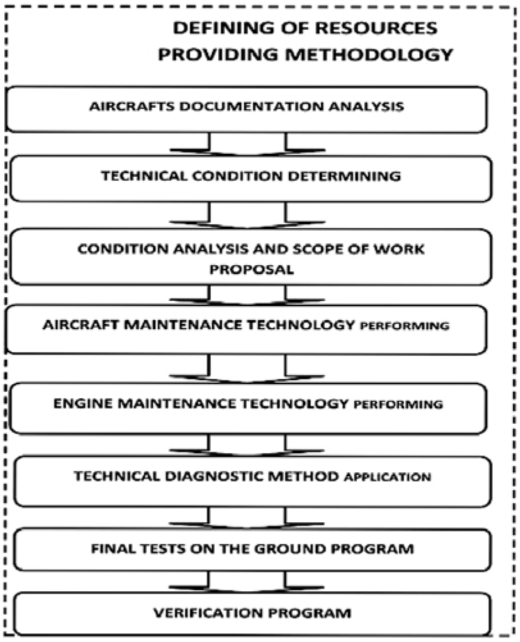

Fig. 4. Diagram of second branch

During this analysis, it is necessary to determine whether the engine, from a technical and technological standpoint, is fulfilling all necessary preconditions for establishing condition-based maintenance (Karadžić 2009).

Instead of them, the manufacturer has introduced the following limitations in resource definition:

- permitted working hours in the air Δ1,
- permitted number of times the engine may be started Δ2,
- permitted working hours in 'maximum' and 'additional combustion' modes Δ3,
- permitted working hours in 'special' mode (increased temperature mode) Δ4,
- pproved aggregate resource Δ5.

2. From a detailed functioning analysis of each engine, it is determined whether, besides the time resource, recommended limitations Δ2 – Δ4 are already used up as well and in what percentage (around 85% would indicate that the engines have certain usable resource reserves).

Although the engines on Montenegrin Army aircraft do not have the modular construction that is used on Western engines, during practical usage it has been proven that they can be disassembled into several modules that then can be replaced without additional testing.

That enables the introduction of a differential life cycle for engine modules and aggregates. This differential life cycle is related to hour resources or for total accumulated cycle.

During the examination of exploitation experiences, the most complicated problems on engines are analysed and identified. Regardless of the complexity and severity of problems, it is a logical decision to continue the exploitation of the engine as long as there is a reliable monitoring mechanism of its condition.

The way failure occurs is not critical for flight safety as long as it is of gradual character and can be controlled, and its manifestation is with the following signs: colour change and increased oil consumption, increased iron and graphite concentration in oil, and shorter period of compressor rotor stopping.

By monitoring of bearing condition through by monitoring bearing condition through the introduction of spectral oil analysis and measurement of vibration and noise, one can discover and record all manifestations on time.

3. Introduction of total accumulated cycles (TAC). In accordance with the main assumptions for calculating total accumulated cycles (see Fig. 5 and corresponding equation) and engine operational limitations specified by the manufacturer, the defining procedure of total accumulated cycles for the engine is carried out.

Total accumulated cycles of a jet engine (on American combat planes) is determined as follows.

$$TAC = nx\, cycle\ type\ I + nx \frac{cycle\ type\ III}{4} + nx \frac{cycletypeIV}{40}. \quad (1)$$

As an extra factor we have moving the throttle handle (for combat airplanes), which causes heat impact on various engine parts:

type 1 – start – increasing to 'maximum' or 'afterburning' – reducing to "STOP";

type 2 – just under 'maximum' – increasing to 'afterburning' – reducing to under 'maximal';

type 3 – 'idle throttle' – 'maximum' or 'afterburning' – reducing to 'idle throttle';

type 4 – 80% (nominal) – 'maximum' or 'afterburning' – reducing to 80% (nominal).

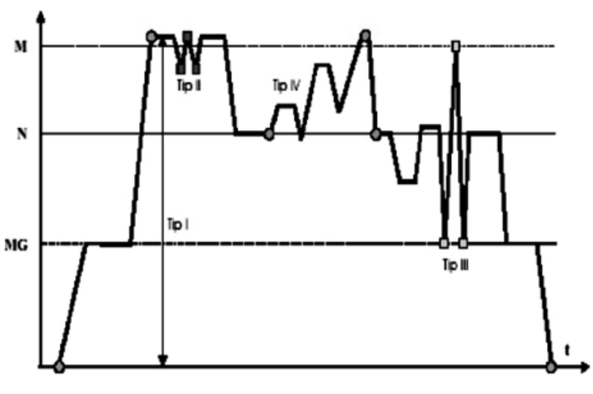

Fig. 5. Main types of total accumulated cycles (MG – idle throttle, N – nominal, M – maximal) (Karadžić 2009)

Cycles of type 1, 2, 3 and 4 are related to the thermal cycle that determines the life cycle of the complete engine, while the type 2 cycle is related to the lifecycle of the afterburning chamber.

By the integration of the main limitations manufacturers prescribe within TAC, orientation (goal) engine resource is defined as number of operating hours and as possible TAC number, which is corrected according to actual total accumulated cycles of each engine separately.

It is important to note that engine resources are not fixed anymore, but after 25 engine operating hours, an inspection of condition and evaluation of technical condition and engine operation parameters are performed. After that, based on the analysis performed, the next usable resource of 25 hours is approved.

Expert knowledge databases of typical failures, their symptoms, and their effects have a key role in deciding about the further use of engines.

The introduction of the engine resource algorithm based on actual total accumulated cycles instead of working hours enables the extension of engine resources while sustaining the same safety level, to significant maintenance cost reduction (Fig. 6).

Modern aircraft engines are exposed to highly complex loads, and because of that one must perform a work analysis on them during the flight and also after each flight and evaluate technical condition.

For the purpose of reliable monitoring of engine condition, it is necessary to establish coordination between these subjects: aircraft company (unit) – aircraft industry – authorised technical facility.

The aircraft company continually monitors the condition of the engine.

Between two evaluations of engine condition that is after 10+5 hours of engine working, additional endoscopic inspection of the primary combustion chamber and high-pressure turbine is conducted and TAC updating is carried out.

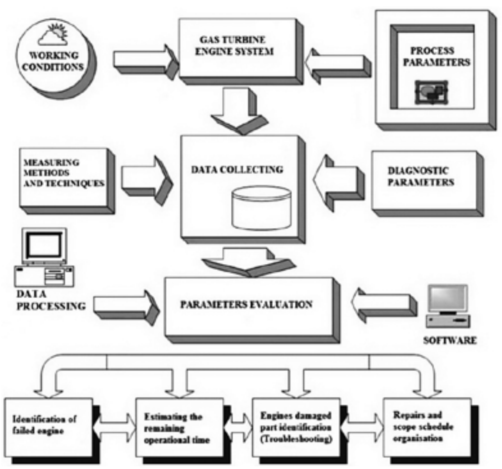

Fig. 6. Methodological approach to parameter diagnostics in maintenance of engines (Karadžić 2009)

Flight parameter analysis is performed from the air flight parameter registrar in two stages.

The first stage or express analysis of flight parameters is performed with a laptop just after the aircraft lands, between two flights for fast inspection of key engine parameters possibly being exceeded.

The second stage or detailed flight parameter analysis is performed after all-day flights, and during analysis one must perform archiving of necessary data and TAC correction.

The aircraft industry (institute) inspects engine conditions by partially dismantling it every 25+5 engine working hours (video-endoscopic + other kinds of non-destructive inspections) as well as evaluating remaining resources.

The authorised technical facility performs a spectral analysis of fuel and oil.

2.3. Aviation information system

The technical system is analysed from strategic, operational and tactical levels of management and planning of the information system through production and data classes based on the decomposition of business processes, in detailed and clear diagrams (Fig. 7) (Karadžić *et al.* 2011).

The general architecture of IS maintenance is defined based on the business processes in maintenance, as relatively the most stable component of the technical system.

A projected informational system is a necessary condition for establishing the new model. The information maintenance system in this work is projected and enables integration into the overall IS of the Montenegrin Army (Fig. 8).

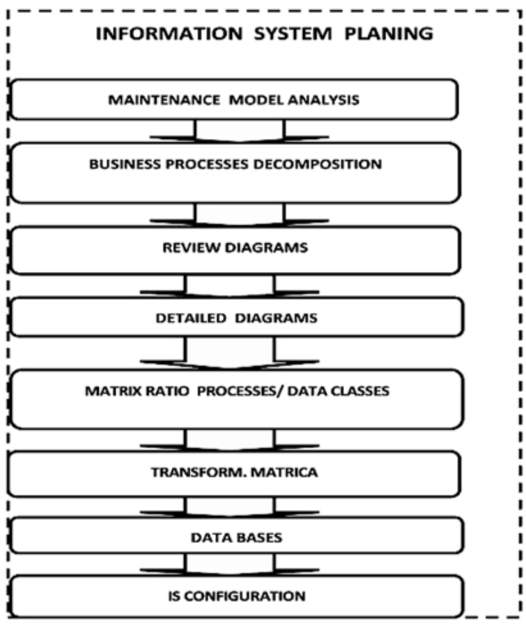

Fig. 7. Diagram of third branch

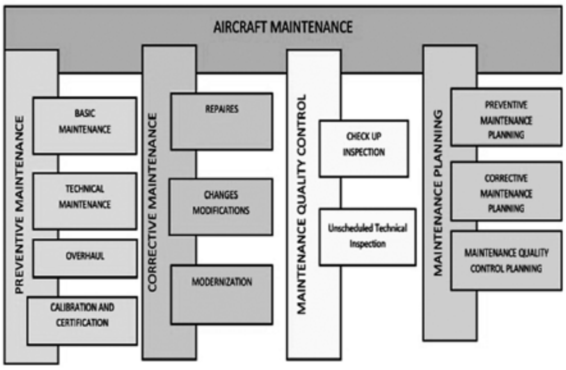

Fig. 8. Diagram of aviation maintenance (Karadžić 2009)

The aviation maintenance system is presented in diagram form through processes and sub-processes.

The aircraft maintenance IS subsystems are:

I – maintenance planning,

II – performance of maintenance activities,

III – quality control of maintenance (Fig. 9).

Aviation maintenance IS subsystems are included in the creation of the database and use data from the DB for their own work.

Based on maintenance characteristics, databases and IS with its components are defined: hardware communication, software, and organisation application components.

The hardware component consists of:

- central computer unit (server)–saving and processing unique user-defined database and depending on the requested degree of safety serves local area networks (LAN) (receiving and sending information);
- local area networks–set of networked computers;
- modem–device that connects local area networks with server. Modems are equipped with data crypto protection;
- telecommunication equipment–already existing equipment (links) built within unique company network.

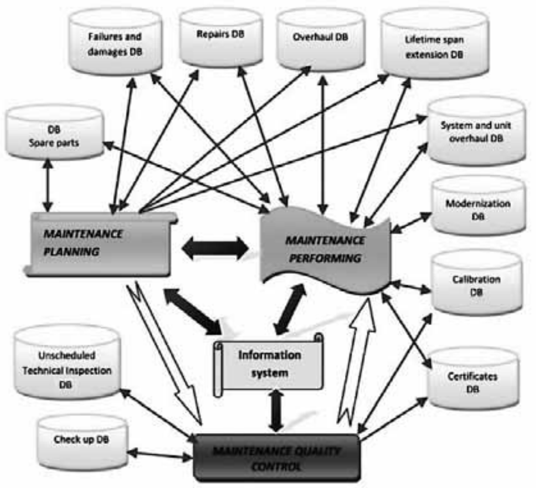

Fig. 9. Maintenance IS relations (Karadžić 2009)

The software component consists of:

- operating system (Windows recommended);
- application-defined databases (MS Access, Oracle, MS SQL, etc.);
- user-defined applications (created for each user, these define data access in some of the database-oriented programming languages (visual basic, C++, etc.);
- communication software–connecting local networks with the main server through already existing and protected company communication lines.

Communication within Logistic IS is achieved Communication within the logistics IS is achieved through the existing airline company communication lines, while communication with external associates goes over the internet; during this connection, no other connections are allowed. Data received from external associates is inputted afterward in the server by maintenance management.

The physical topology of IS maintenance is projected in a 'star-shaped' model because that is the best way to achieve better disturbance resistance of the IS; the failure of one unit does not lead to system failure.

The IS of maintenance consists of three subsystems: the subsystem of planning maintenance, subsystem of conducting maintenance, and subsystem of maintenance quality control.

The essence of the model is represented by the database (or database system), which consists of interrelated data.

2.4. Organisation of condition-based diagnostic maintenance

The organisation of condition-based diagnostic maintenance of aircraft and appropriate systems according to technical condition demands the application of modern diagnostics, which can be divided into three parts (Jaźwiński, Żurek 2002).

Operational diagnostics: This allows extending normal exploitation (functional system) or defines the procedure for additional control (inoperative system) (Fig. 10). These tasks are always performed at the end of the flight day.

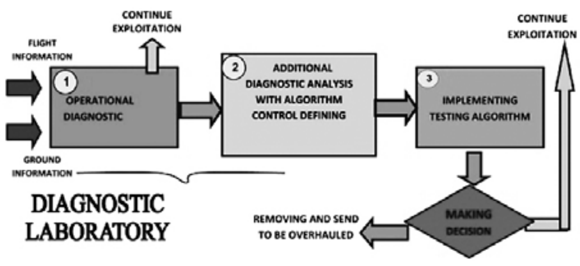

Fig. 10. Structural diagram of diagnostics in aircraft exploitation (Karadžić, Bulatović 2010)

Additional diagnostic analysis with defining the testing algorithm: This contains the algorithm of procedures for system test, without removing the system or elements from the aircraft.

Implementing the testing algorithm according to maintenance procedures: Implementing this diagnostic algorithm is performed by experienced specialists according to maintenance procedures, along with making a decision about whether to continue exploitation or send the item for an overhaul.

2.5. Integration of methodology

Proposed condition - based model for aircraft maintenance would look like at the Fig. 11.

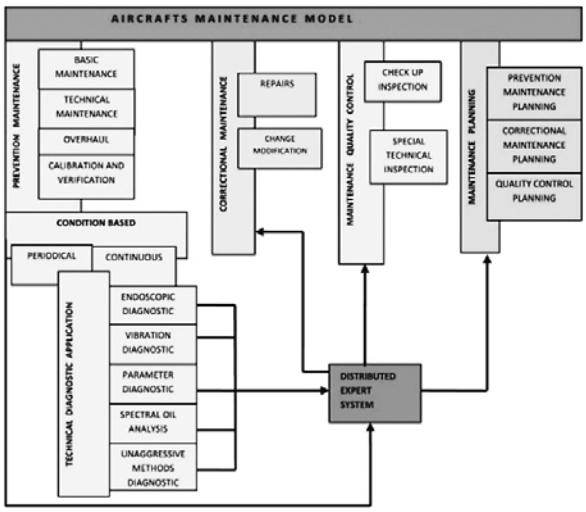

Fig. 11. Proposed maintenance model diagram for aircraft

3. Example of systematic diagnostics

The selection of critical ways is conducted by ABC analysis, and the priority of solving specific problems is obtained.

From the diagram, using ABC analysis on a Gazelle helicopter, which is a part of the Montenegrin Army, two systems with the sum of 65.15% of total helicopter failures are distinguished.

SYSTEM I – transmission and rotors, with 37.41% of participation, represents the most critical spot and is extremely important from the aspect of analyses and increase in helicopter efficiency.

SYSTEM II – the engine participates with 27.74% of total helicopter failures.

Data processed in the past is the foundation for reaching long-term decisions. Based on the nature of primary and secondary events, parameters are defined for tracking the diagnostic condition of system parts.

From 2005–2010, planned measures for the maintenance of critical helicopter systems maintenance were undertaken for the purpose of advancing maintenance efficiency (defining weak spots and priorities in correcting them by using appropriate methods (Fig. 12–15) (Karadžić 2009).

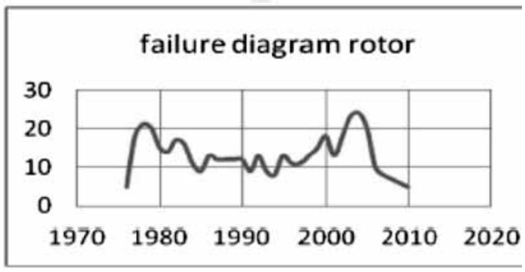

Fig. 12. Helicopter rotor system failure diagram

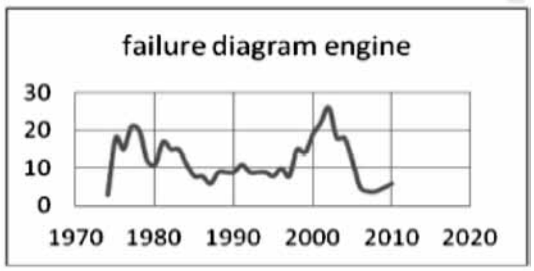

Fig. 13. Helicopter engine system failure diagram

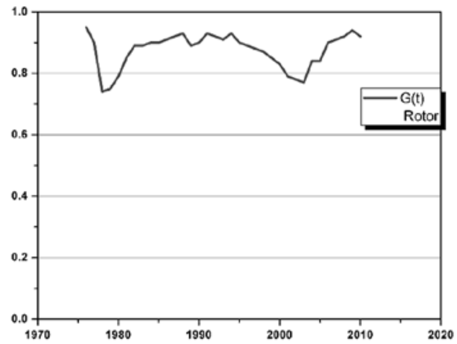

Fig. 14. Helicopter rotor system readiness diagram

$$k_{OG} = \frac{\sum T_r}{\sum T_r + \sum T_0} = \mathbf{0.86}. \quad (2)$$

From the diagram, one can notice a decrease in failures over the past 5 years, in other words since the application of condition-based maintenance.

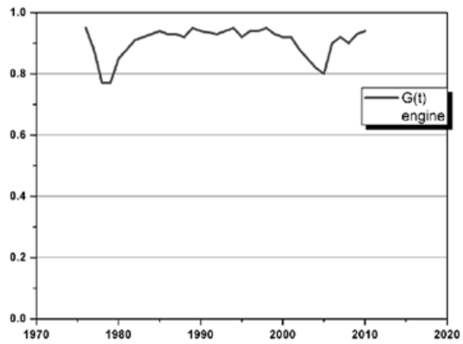

Fig. 15. Helicopter engine readiness diagram

$$k_{OG} = \frac{\sum T_r}{\sum T_r + \sum T_0} = \mathbf{0.89}. \quad (3)$$

During this period, the research results showing operational readiness of rotor systems and transmissions increasing from an average of 0.86 (from 1974–2004) to 0.93 (2005–2010) with the systematic application of technical diagnostic methods (Karadžić 2009). Over the same period, engine readiness has increased from 0.89 to 0.95 (Fig. 16–17) (Karadžić 2009).

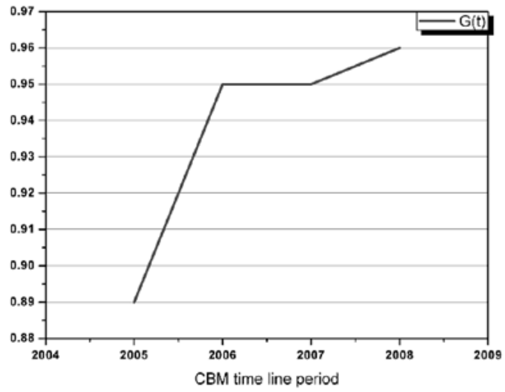

Fig. 16. Rotor change readiness diagram

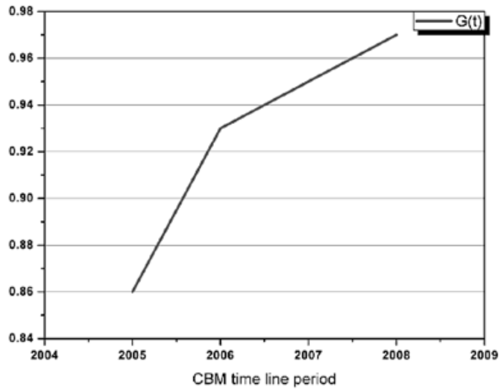

Fig. 17. Engine change readiness diagram

Analyses show that by monitoring condition parameters with continual and periodical check-ups of system components, in other words with diagnostic methods, operational readiness of aviation systems can be increased.

Such results of reliability point out the necessity and comfort of applying condition-based maintenance with systematic diagnostics on critical aircraft systems as a way of solving problems.

4. Conclusion

1. The selection of a quality aircraft maintenance model selection is presented in this paper by considering the specifics of helicopters and airplanes and the requirements and maintenance possibilities in aviation in a small country, Montenegro. To maintain aircraft rationally, a specific maintenance model is created. This model consists of three branches and exploits the possibility of applying new methods of technical diagnostics in order of monitoring aircraft condition and prolong the life cycle of aircraft.
2. For the aircraft that were under a limited lifespan maintenance concept, a new condition-based maintenance model was developed by applying a technical diagnostic method that yielded decreasing numbers of failures in the ageing period of those technical systems and at the same time decreased downtime and lowered maintenance expenses.
3. An information system for monitoring aircraft operation was also developed. This system is compatible with systems already installed for the permanent monitoring of crucial systems, from the phase of collecting and reading of data to the analysis of operating parameters, which will improve any deviation from normal trends, all in pursuit of the main goal, which is to predict possible failures of the systems that are monitored.
4. Analyses of this model conducted through researches made clear its justification to preserve operational readiness and possibilities to decrease expenditures in the maintenance of aviation systems. With the application of the proposed model, it is expected to increase the efficiency of tracking the condition of systems, which will enable complete and fast preparation of maintenance elements, creating conditions for maximal exploitation of the individual technical possibilities of aircraft systems while preserving functionality.

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