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PRESENTATION OF AIRCRAFTS CONDITION BASED MAINTENANCE MODEL

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Abstract: Aircraft qualitatively maintenance model selection is presented in this paper (*Condition Based Maintenance*) considering the specifics of helicopters and airplanes, requirements and maintenance possibilities in aviation of a small country, which is Montenegro. In order to maintain airplanes rationally maintenance specific model is created and base of this model consists of three branches, depending on possibility of applying new methods of technical diagnostic, in order of monitoring the aircraft condition and necessity of aircrafts prolonged life cycle. Pilot analyses of this model realized through researches presented its justification in order to preserve operational readiness and possibilities for expenditure decreasing in maintenance of aviation systems.

1. INTRODUCTION

Maintenance of planes and helicopters in Montenegro was conducted (and still is) according to working hours of an aircraft. After expiration of proposed working hours manufacturer recommends overhaul of subsystem set which is send to aviation factories for overhaul [1].

Great financial means are necessary for overhauls as well as long period of time. All this means that aircraft will be out of use for long time which is unacceptable considering their purpose [1].

Due to use of new materials and new technologies existing concept of maintenance has become pretty uneconomical and inflexible so modern aviation systems and big industries are changing their approach from old system of maintenance to new concept, condition based concept [2].

Conventional modes of maintenance such as corrective and preventive are not appropriate for fulfilling demands on high cost and high usable systems. New strategies are based on assumptions of degradation through demanded expected process.
Aircrafts in The Army of Montenegro are in third period of their life cycles. Concerning maintenance of the “aged” aircrafts there is a new trend in the world, extension of their life cycles. [3], [4].

Aircrafts can be used longer than their recommended life cycle if firstly recommended lifespan can be described in details and all damages can be often inspected during extended use of aircraft. 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.

It must be mentioned that concrete model of application of this CBM concept of “aged” aircrafts is not standardized because it is protected by big countries as their ownership, which says enough about complexity of this problem.

Development of condition based maintenance model represents complex and insufficiently researched field in small countries because of the limited conditions.

This paper presents approach to development of condition based maintenance of aircrafts in order to improve aircraft maintenance in the limits and conditions of small countries and in accordance to world technological achievements.

2. MAIN CHARACTERISTICS OF NEW MODEL

New model has three “branches”:

- First branch represents methodology analysis defining of technical diagnostic for aircraft maintenance.
- Second branch represents methodology defining for providing of resources for aircraft maintenance,
- Third branch represents projecting of informational system for aircraft maintenance.

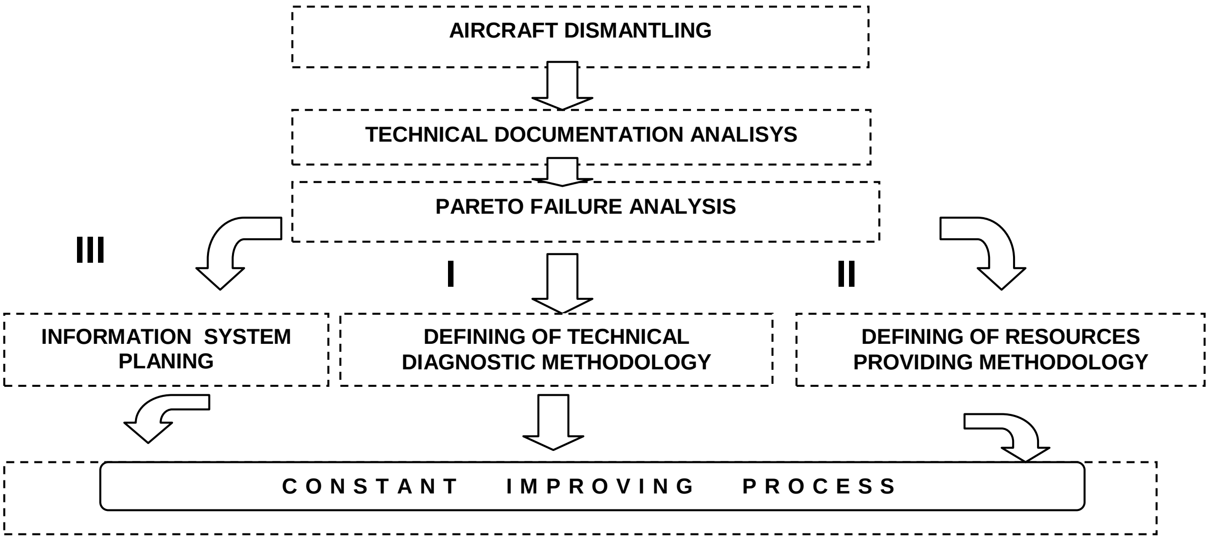


Figure 1. Diagram of basic Condition Based Maintenance model

2.1. FIRST BRANCH

First branch represents analysis of the systems for which there is no methodology of applied technical diagnostic (marked with I on the figure). Separation is conducted on the criteria of existence of use of the method of technical diagnostic on aircrafts critical systems as part of defined maintenance in previous period.

Detailed application of method of endoscopic vibration diagnostic of fuel and lubrication, destruction free diagnostic method according to “disciplined” methodology is suggested. Methodology is starting from zero and is very detailed which means that it is developed as if currently nothing is performed like anticipating, prevention or detection of failure. By performing this procedure, systematic searching of system and covering all unknown is enabled. Depending on construction specificity and complexity of aircraft there shall be five main diagnostic methods in use: Application of endoscopic diagnostic enables tracking of changes which are occurring within appliances of aircraft and they are the cause of appliance condition parameter change. All these unwanted occurrences can be noticed and recorded without dismantling the device[5]. Application of vibration diagnostic can show condition of air systems and point out the early stage of failure [6],[7].

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 appliance. Depending on percent and content of metal particles it is possible to figure out is there wearing out of some movable parts and what is the quality of their lubrication [8],[9].

With spectral analysis of aircraft fuel we can notice the changes of physics chemical characteristics of fuel which can have negative impact on functionality, especially on engine, power and throttle, in other words combat readiness of an aircraft.

With application of these diagnostic non-destructive analysis methods it is possible to detect corrosion and cracks as well as changes on frame joints with front part of the fuselage, with tail cone etc. [5],[10].

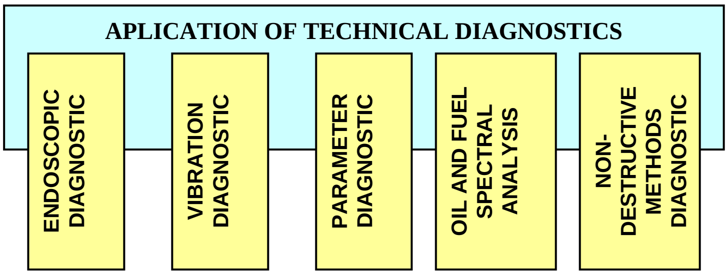


Figure 2. Main diagnostic methods in Condition Based Maintenance concept

For diagnostic application it is necessary to have diagnostic object construction knowledge.

After detailed introduction and analyses of object construction, inspection points, which will be diagnosed, must be defined.

Choice of diagnostic equipment depends on the chosen checking points, constructive solutions of the checking openings, and conditions in which check up will be performed, etc.

Diagnostic procedures are defined after defining of checking points, selection of accessible holes and diagnostic equipment selection.

An analysis of allowed damages is one of the most important phases of diagnostic in order to reach a decision about continuation of object exploitation. For evaluation of damages acceptability most often is used method of comparison with standard (acceptable) damages on corresponding objects part. Report with solution proposal is created on the basis of reviewed data and analysis of registered damages.

2.2. SECOND BRANCH

Second branch works on detailed methodology for providing of resources.

Starting point on these systems is taken from already used maintenance so in analysis it is possible to rely on experience of operators. There is big problem in personnel, material and time resources which 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 group of systems which are recognized as weak spots based on Pareto analysis.

Methodology of extending of resources consists of following phases:

1. aircraft documentation analysis,
2. determining of aircraft technical condition,
3. aircraft technical condition analysis along with scope of work proposal,
4. performing of aircraft condition based maintenance technology,
5. performing of engine condition based maintenance technology,
6. technical diagnostic method application program,

7. final tests on the ground program,
8. verification program.

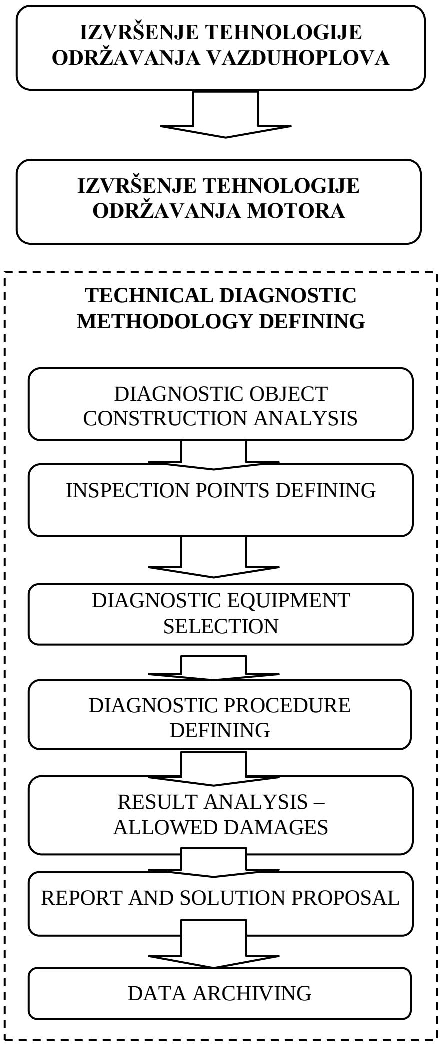


Figure 3. "I" branch diagram

Application methodology of maintenance procedure according to aircraft engines condition.

[1] Starting element of assessment of 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, RB-199, PW1120 and F-404) [14],[11]. During this analysis it is necessary to determine whether new engine, from technical-technological standpoint, is fulfilling all necessary preconditions for establishing condition based maintenance.

Basic problem with aircraft motors of I and II generation is lack of information on their characteristic and number of permitted load cycles during the exploitation. Instead of them manufacturer has introduced following limitations in resource definition:

- Permitted working hours in the air $\Delta 1$;
- Permitted number of engine starting $\Delta 2$;
- Permitted working hours on modes "maximum" and "additional combustion" $\Delta 3$;
- Permitted working hours on "special" mode (increased temperatures mode) $\Delta 4$;

- Approved aggregate resource ∆5.

[2] From detailed functioning analysis of each engine it is determined are there beside time recourse, recommended limitations ∆2 - ∆4 already used up as well and in what percentage (around 75% would indicate that engines have certain usable recourse reserve).

Although engines on Montenegrin Army aircrafts aren't modular construction which is applied on western engines, during practical usage it is proven that they can be disassembled on several modules which than can be replaced without additional testing. That enables introduction of differential life cycle for engine modules and aggregates. This differential life cycle is related to hour resource or for total accumulated cycle.

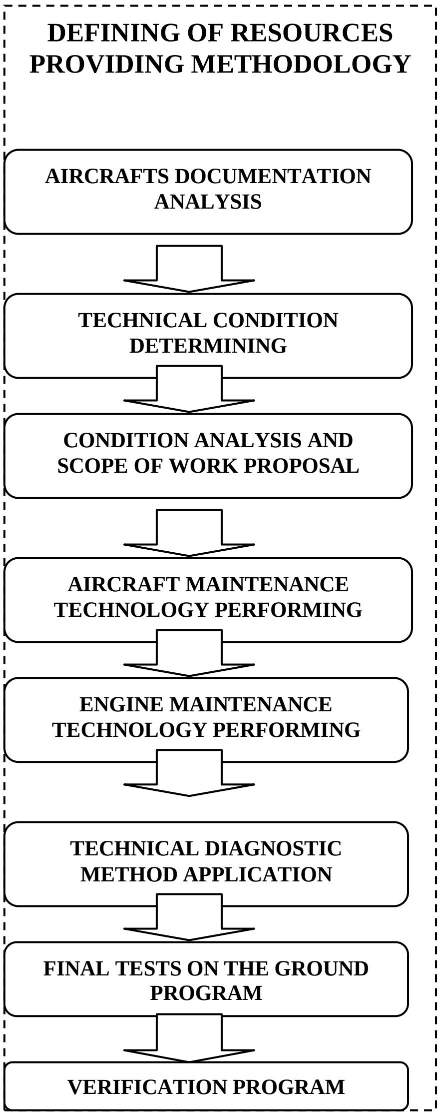


Figure 4. Branch "II" diagram

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

The way how failure is occurred is not critical for flight safety as long as it is of gradual character and can be controlled, and its manifestation is with following signs:

colour change and increased oil consumption, increased iron and graphite concentration in oil, shorter period of compressor rotor stopping. By monitoring of bearing condition through introduction of spectral oil analysis, measurement of vibration and noise, all manifestations can be discovered and recorded on time.

[3] *Introduction of total accumulated cycles (TAC)* **-** In accordance with main assumptions for calculating of total accumulated cycle (see fig 4. and corresponding equation 1.), and engine operational limitations introduced by manufacturer, it is started defining procedure of total accumulated cycle for listed engine [14],[11].

Total accumulated cycle of jet engine (on American combat planes) is determined as follows:

$$TAC = n \times \text{cycle type I} + n \times \frac{\text{cycle type III}}{4} + n \times \frac{\text{cycle type IV}}{40}$$

As an extra factor we have moving of throttle handle (for combat airplanes) which is causing heat impact on various engine parts:

Type 1 – start – increasing to "maximal" or "afterburning" – reducing to "STOP"
Type 2 – just under "maximal" - increasing to "afterburning" – reducing under "maximal"
Type 3 - "small throttle" - "maximal" or "afterburning" – reducing to "small throttle"
Type 4 - 80% (nominal) - "maximal" or "afterburning" – reducing to 80% (nominal)

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

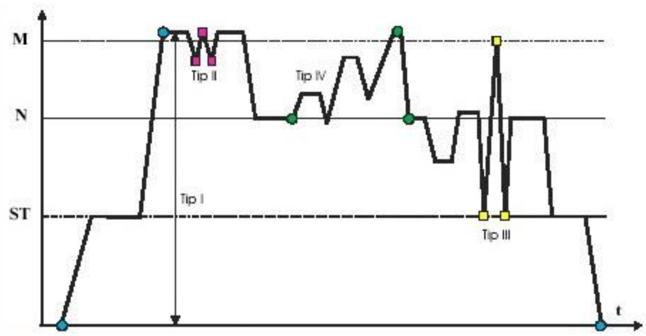


Figure 5. Main types of total accumulated cycles (ST-small throttle, N-nominal, M-maximal)

By integration of manufacturers prescribed main limitations within TAC, orientation (goal) engine recourse is defined expressed as a operative hours number and as possible TAC number, which is corrected According to real total accumulated cycle of each engine separately.

It is important to notice that engine recourses are not fixed anymore, but after usage of 25 engine operational hours is performed condition inspection and technical condition evaluation and engine operation parameters after that based on the performed analysis it is approved next usable recourse of 25 hours. During this operator have information of maximal possible remaining of usable engine recourses.

Expert knowledge databases of typical failures, their symptoms and effects have key role in decision of further engine usage.

By introducing the engine recourse algorithm based on real total accumulated cycles, instead on working hours, enables the extension of engine recourses with sustaining the same safety level, valid useful recourse remain evaluation and significant maintenance cost reduction.

Modern aircraft engines are exposed at highly complex loads, and because of that one must perform their work analysis during the flight and also after each flight and evaluate technical condition (Figure 6).

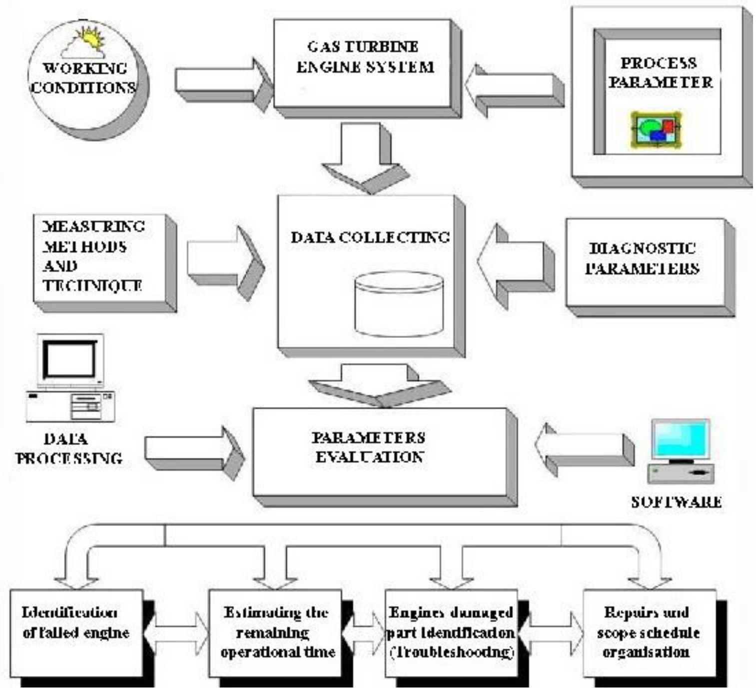


Figure 6. Methodological approach to parameter diagnostic in maintenance of GTE

For the purpose of reliable monitoring of engine condition it is necessary to establish coordination between these subjects: Aircraft Company (unit) – Aircraft Industry – Authorized Technical Facility.

Aircraft Company is performing continual monitoring of engine condition parameters. Between two evaluations of engine condition that is after 10+5 hours of engine working additional endoscopic inspection of primary combustion chamber, high pressure turbine and TAC updating is conducted. Flight parameter analysis is performed from air flight parameter registrar in two stages. First stage or express analysis of flight parameters is performed with lap-top just after aircraft landing, between two flights for fast inspection of possible engine work key parameters values exceeding. Second stage or detailed flight parameters analysis is performed after all day flights, and during analysis one must perform archiving of necessary data and TAC correction.

Aircraft Industry (Institute) is performing engine condition inspections with partially dismantling the motor on every 25+5 of engine working hours (video-endoscopic + other kinds of non-destructive inspections) as well as evaluation of remaining resources.
Authorized Technical Facility performs spectral analysis of fuel and oil.

2.3. THIRD BRANCH

Technical system is analyzed from strategic, operational and tactical levels of management and planning of IS through production and data classes based on business processes decomposition, in detailed and clear diagrams.

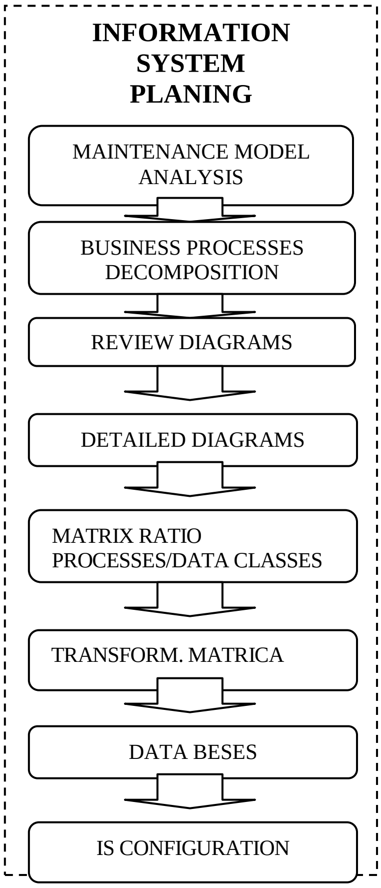


Figure 7. "III" branch diagram

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

Projected Informational System is a necessary condition for establishing the new model of POPS. Informational maintenance system in this work is projected by combining BSP and HIPO method which makes it insensitive on real system structure changes and enables integration in global IS of Montenegrin Army. Physical topology of IS maintenance is projected in the "star shape" model because that is the best way to achieve better disturbance resistance of IS, failure of one unit doesn't lead to system failure.

IS of maintenance consists of three subsystems: subsystem of maintenance planning; subsystem of maintenance conducting; subsystem of maintenance quality control.

The essence of the model is represented by data base (or data base system) which consists of interrelated data [13].

2.4. ORGANIZATION OF CONDITION BASED DIAGNOSTIC MAINTENANCE

Organization of condition based diagnostic maintenance of aircraft and appropriate systems according to technical condition, demands application of modern diagnostics which can be divided on:

a. Operational diagnostics – Provides extending of normal exploitation (functional system) or defines procedure of additional control (inoperative system). These works are always performed at the end of flight day.

b. Additional diagnostic analysis with testing algorithm defining – Contains algorithm of procedures for system test, without removing the system or elements from the aircraft.

c. Implementing testing algorithm according to maintenance procedures – Conducting of this diagnostic algorithm is performed by experienced specialists according to maintenance procedures, along with making a decision about continuing of exploitation or sending for an overhaul.

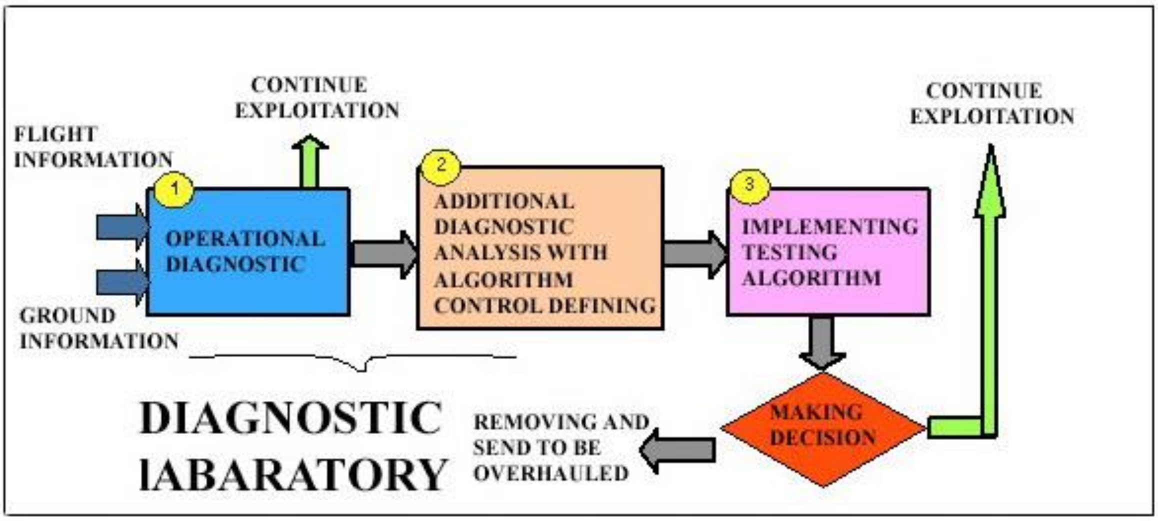


Figure 8. Structural scheme of diagnostics in exploitation of aircrafts [12]

2.5. INTEGRATION OF METHODOLOGY APPLICATION

By integrating the elements of an existing model, suggested model of preventive condition based maintenance would be used [13].

For the purpose of reliable monitoring of aircraft system condition it is necessary to establish distributed expert system related to:

- Aircraft Company – parameter, partially endoscopic and vibration diagnostics
- Aircraft Industry (Institute) – endoscopic, vibration and non-destructive methods diagnostics
- Authorized Technical Facility – spectral analysis of fuel and lubrication oil

3. APPLICATION EXAMPLE OF SYSTEMATIC DIAGNOSTICS ON SYSTEMS WEAK SPOTS

Selection of critical ways is conducted by ABC analysis and priority of solving specific problems is obtained.

From the diagram, using ABC analysis on helicopter Gazelle which is a part of Montenegrin Army, two systems with the sum of 65,15% of total helicopter failures are distinguished.

I SISTEM: - Transmission and Rotors with 37,41 % of participation represents the most critical spot, also represents peak event from the aspect of analyses and increasing of helicopter efficiency.

II SYSTEM – GTE Engine participates with the sum of 27,74% of total helicopter failures

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

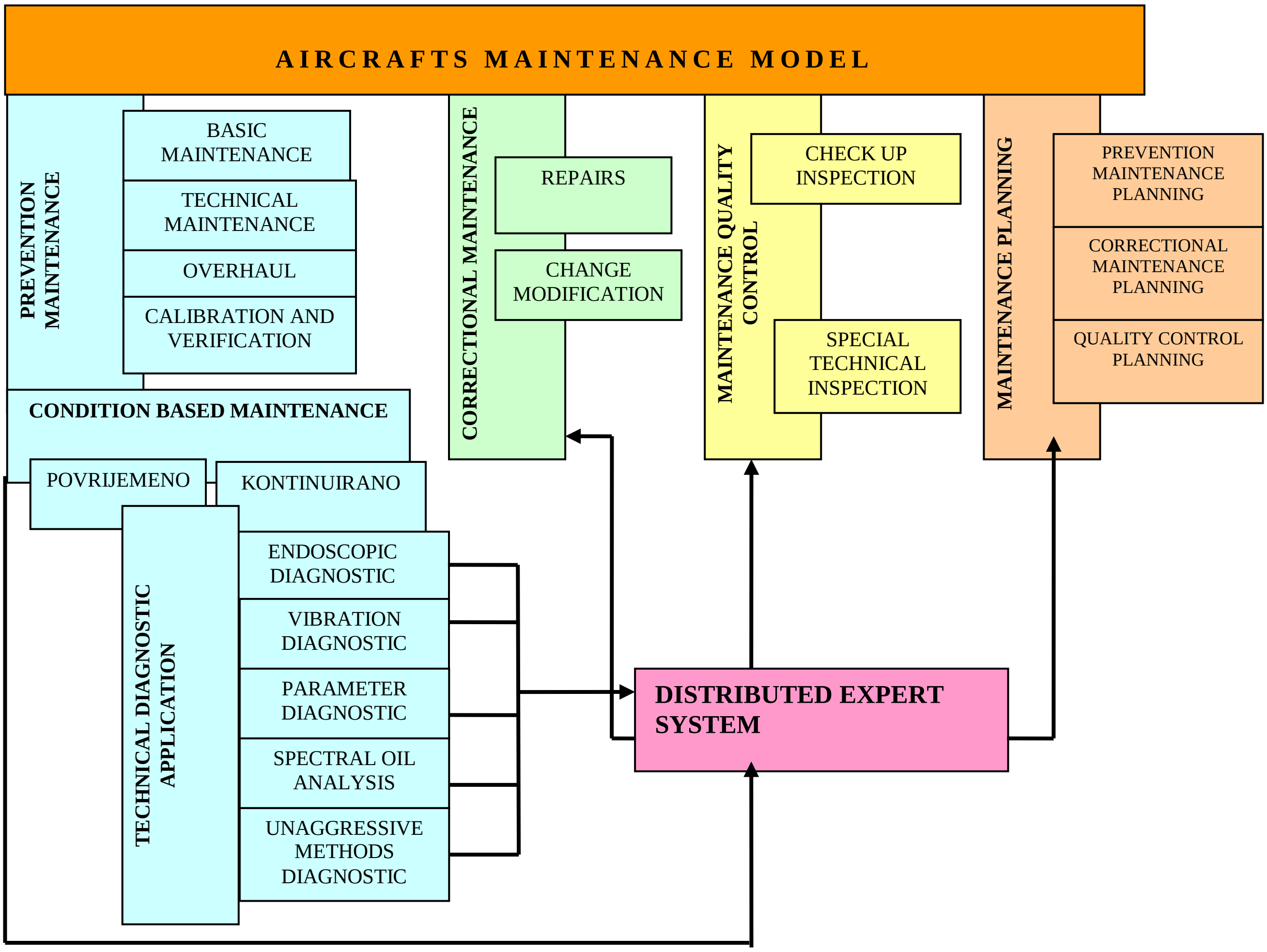
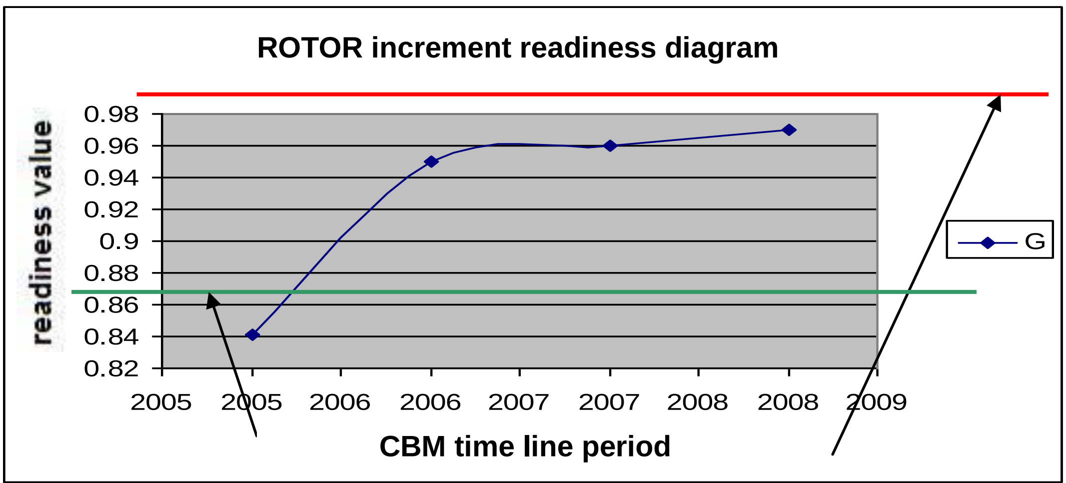


Figure 9. Proposed maintenance model diagram of Montenegrin Army aircrafts [13].

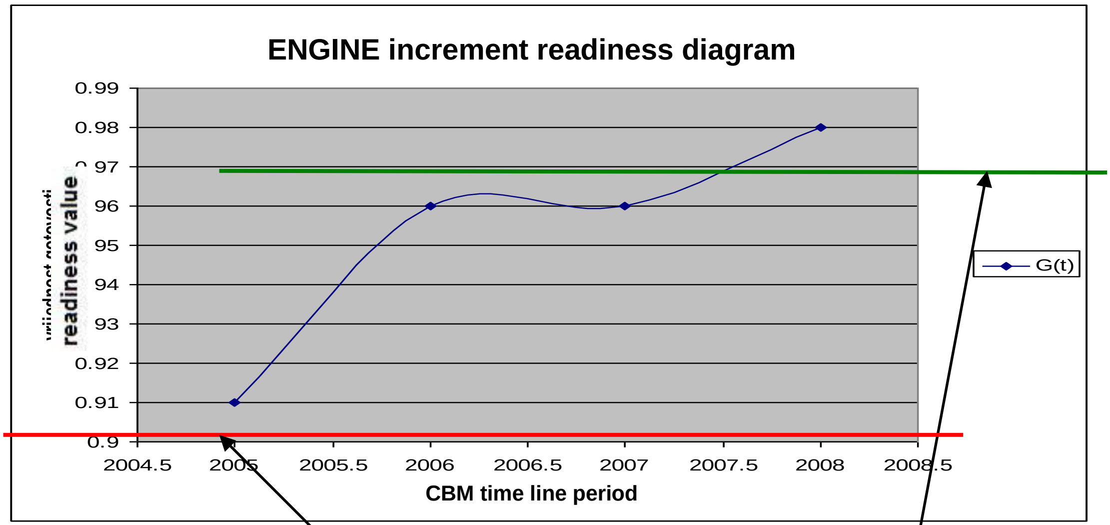
From 2005-08 planned measures for helicopter critical systems maintenance are undertaken for the purpose of advancement of maintenance efficiency (defining of weak spots and priorities in correcting them by using appropriate methods, introducing specific ways of technical diagnostic that is condition based maintenance).



$k_{OG\ \text{"1974-2005"}} = \frac{\sum Tr}{\sum Tr + \sum T_o} = 0{,}835$ $\qquad$ $k_{OG\ \text{"2006-2008"}} = \frac{\sum Tr}{\sum Tr + \sum T_o} = 0{,}96$

Figure 10. Helicopter Gazella rotor readiness diagram

During this period the research results are showing operational readiness increasing of Rotor systems and Transmission from average 0.835 (from 1974-2004) to 0.96 (2005-2009) of systematically application of technical diagnostic methods [13].



$$k_{OG\ "1974-2005"} = \frac{\sum Tr}{\sum Tr + \sum T_o} = 0{,}890 \qquad k_{OG\ "2006-2008"} = \frac{\sum Tr}{\sum Tr} = 0{,}97$$

Figure 11. Helicopter Gazella engine readiness diagram

Analyses are showing that by monitoring of condition parameters, with continual and periodical checkups of system components in other words, with diagnostic methods, operational readiness of aviation systems can be increased.

Such results of reliability are pointing out the necessity and comfort for application of condition based maintenance with systematic diagnostic on aircrafts critical systems as a way of solving problems.

4. CONCLUSION

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

While setting the model it was made balanced approach by depth and width in three parallel analysis directions.

Pilot analysis based on this model showed applicability, preservation of the operational readiness and potential for cost decreasing of aircraft maintenance.

With application of proposed model it is expected to increase the efficiency of system condition tracking, which will enable complete and fast preparation of maintenance elements, with which are made conditions for maximal exploitation of individual technical possibilities of aircraft systems, with preserving of functionality.

Maintenance model based on technical diagnostic, computer assistance, TQM concept and also integrated in maintenance informational system, enables effectiveness preservation, cost saving, rationalization of maintenance actions and easy adoption of maintenance for modern and technically more complexes aircrafts in the future.

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