TRANSPORT SYSTEMS

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MAINTENANCE INTERVALS APPOINTMENT ON THE BASIS OF MODEL OF AIRCRAFT SYSTEMS FUNCTION STATE CHANGING

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Abstract—*This paper presents a novel approach of determining optimum intervals for aircraft maintenance. The Model of aircraft systems function state changing, offered by authors, makes possible to provide information to determine the volume, composition and execution intervals of aircraft maintenance and also enable to take into account changing components condition in an integrated manner, caused by either operating time, or service period, to determine requirements to aircraft maintenance work volume and content.*

Index Terms—Maintenance program; function state changing; reliability program.

I. INTRODUCTION

Aircraft construction should make impossible failures to appear or provide conditions for failure consequences not to have influences on safety (failures possible to foresee are meant).

Failure consequences are considered as basic factor either for maintenance program creation or for pilot reaction speed to failure information. Aircraft operators are responsible for construction safety preservation and dangerous failures prevention. It should be achieved by maintenance program.

With the increasing need to reduce maintenance costs and increase aircraft availability, the need to simplify the way maintenance is planned and executed has become a major issue in the aircraft industry. Aircraft manufacturers continue to develop aircraft with a low maintenance demand, while operators strive to keep their maintenance costs as low as possible.

The frequency, with which maintenance is performed, determines, to a great extent, the amount of man-hours and materials needed for each maintenance visit. The maintenance frequency also dictates the amount of down time needed for maintenance.

II. PROBLEM STATEMENT

The amount of labour (man-hours) and materials spend on (routine and non-routine) maintenance directly determines the direct maintenance costs.

As pertains to costs arising from aircraft downtime, (Fig. 1) below can be used to elaborate this.

In block 3 above, the aircraft is withdrawn from operation in order to provide for maintenance downtime. This un-availability may be considered as a loss in terms of possible seats that could have been available for sale if the aircraft was in operation.

In blocks 4 and 5, the aircraft is un-available due to technical reasons, and this leads to inevitable losses in terms of production (seats, flight hours). Further, additional maintenance resources have to be provided for in order to make the aircraft serviceable again.

On the other hand, if maintenance was to be performed in block 2, there will be no losses experienced in terms of aircraft un-availability, owing to the fact that the aircraft is not needed in that block. No maintenance is performed in block 1.

Indirect maintenance costs can vary greatly because these mainly depend on the maintenance organisation. On the other hand, direct maintenance costs of an aircraft can be viewed as more systematic and controllable costs.

From a maintenance-planning point of view, a reduction in the total cost of ownership can be achieved by:

– minimisation in the total maintenance work done on an aircraft by avoiding unnecessary repetition of maintenance tasks;

– minimisation in the total maintenance down time.

That’s why, there is a need to determine optimum intervals (Fig. 2) for both line and base maintenance scheduling.

III. PRINCIPLES AND DIFFICULTIES OF AIRCRAFT MAINTENANCE INTERVALS PLANING

Modern maintenance program formation principles provide three basic methods of aircrafts systems states control aiming to keep reliability and safety:

– hard time (laborious, determines the actual state of the product only after decommissioning);

– on condition (does not provide the opportunity to plan maintenance tasks, not applicable to all systems of the aircraft);

– condition monitoring (applicable only for systems that do not affect the safety or requires a reliable backup systems components).

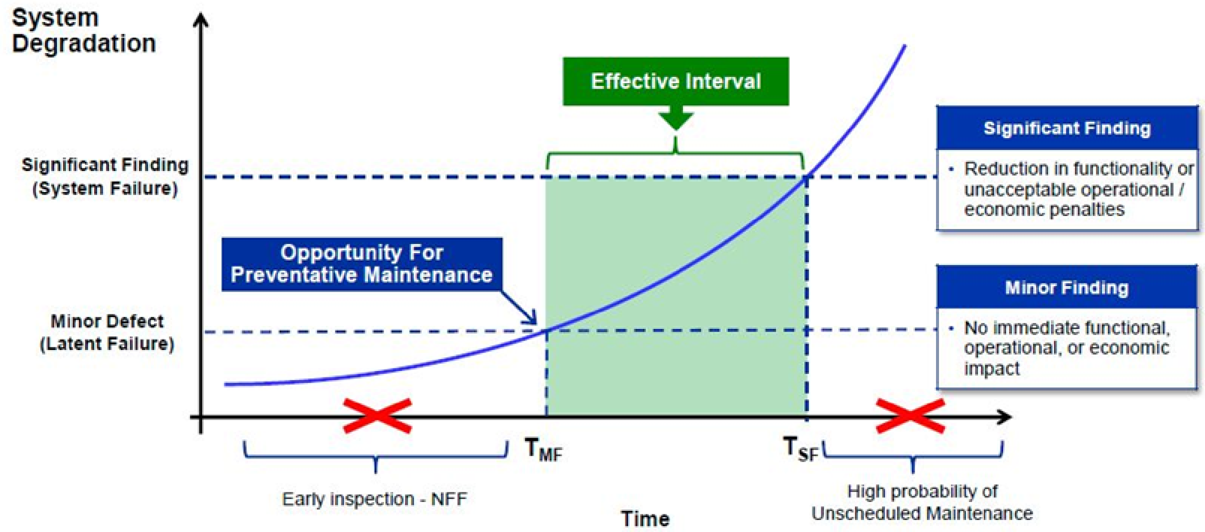

Fig. 1. Maintenance downtime in relation to the cost of maintenance [1]

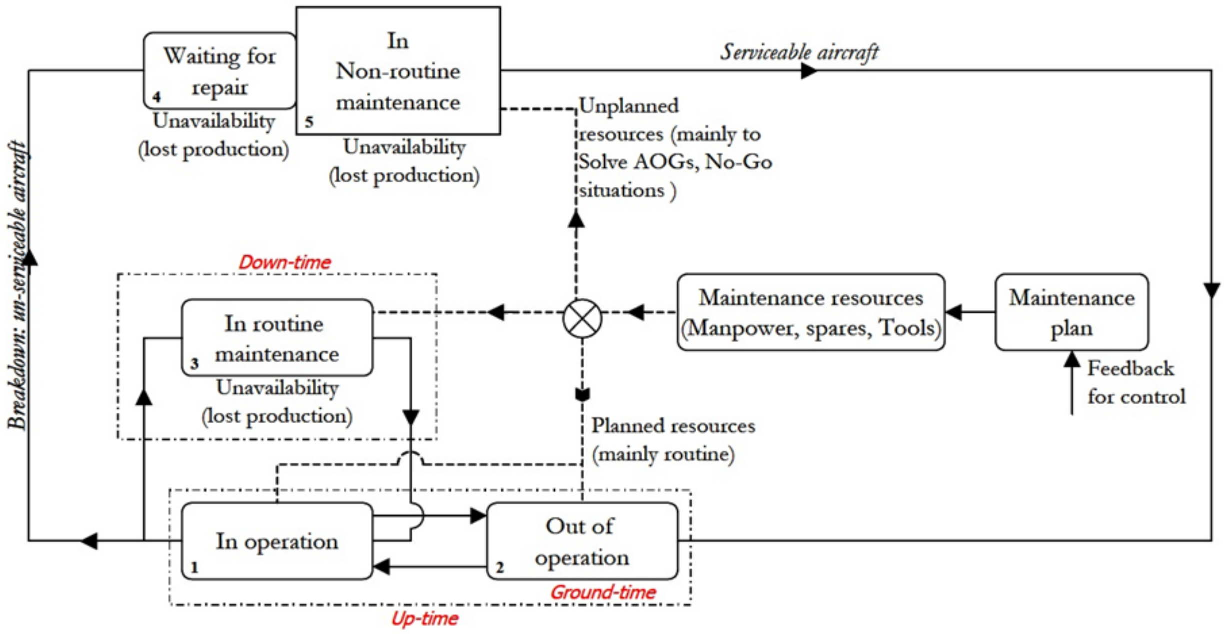

Fig. 2. Setting Optimal Maintenance Intervals. Minimize Looking Too Early (NFF) and Too Late (In-Service Failures, Unscheduled Maintenance)

Condition monitoring requires two basic conditions:

– presence of onboard equipment product failure indication (registration) on the aircraft or automatic switching to reserve at flight and possibility of its early detection at checking functioning operation before using.

– existence of dependability managing system of aviation technique (or its specific parts) in the link production-operation, which allows to plan reliability level, get information about actual reliability level, equate actual level with the planned (set) carrying out control measures and providing set reliability level.

Thus, the condition monitoring principle contains not only approach of determining certain types of works, but also the principle of establishing of the operating limits of the product before sending it to overhaul or taking out of service.

Under real conditions maintenance program of product usually includes various types of work at any one of three maintenance strategies.

The rational maintenance strategy is carried out with the specially developed guidelines. Most widely used manual is MSG-3. MSG-3 contains Reliability Centered Maintenance (RCM) principles and allows:

– focus on the selection of specific maintenance activities;

– estimate the applicability of works, based on the failure characteristics;

The purpose of this manual is worded as follows:

– retain the essential, that is pledged at the manufacturing of product, operational dependability;

– restore essential pledged at the manufacturing of products, dependability and safety levels to their initial values in case of failure;

– obtain the information, necessary to improve product construction, dependability of which is insufficient;

– achieve the greatest degree of safety at the lowest possible costs for maintenance and costs, associated with canceled flights.

According to the RCM, construction of aircraft must exclude the possibility of failure or provide such conditions, under which the consequences of failure must not affect at safety (means only those failures, which can be foreseen).

Signs, which characterize pledged dependability, according to RCM, are:

– influence of failure consequence at the safety, operational dependability, operational capabilities and maintenance costs;

– exposure to secondary defections as a result of certain types of failures;

– ability to detect potential failures with the aim to prevent functional failures;

– severity of failure consequences functionally related items;

– signs, by which can be found that the failure actually occurred;

– failures intensity;

– lifetime influence on the failure probability;

– costs of prevention maintenance works;

– costs of works for repairing failure.

However, the practical application of RCM for aircraft operators may occur following difficulties.

1. Techniques for determination of quantitative dependability values are based on studying mechanical, physical and chemical properties and parameters of different types of aircraft components that allows to identify components aging processes regularities with time and determine analytical relationship of this regularities with dependability values.

2. Significant disadvantage of these methods is necessity to collect a large amount of statistical information. Thus, according to data, provided in [2], reliable ratings of aircraft components failures intensity for 2–3 years operation can be obtained by analyzing 100–400 aircraft operations only for components that have time between failures of around 800–1500 hours.

3. Aircraft component's failure information is extremely important for effective maintenance planning. But in real operator activity conditions there are some problems with current aircraft system state evaluation, namely: limited failure diagnosis time, lack of equipment necessary for effective concrete element state evaluation, human factor influence on failure detection work results.

That is why there is a necessity to know aircraft system's technical state peculiarities beforehand in order to make corresponding equalizing measures to detect failures and resumption of their work state or deduction.

Therefore proposed, in the case of information deficit for making effective decision on the maintenance works appointment, based on RCM, to use the techniques based on the prediction of aircraft components technical state.

Modern scientific approaches of wear and aging evolution processes description, taking place in complex technical systems, are based on observational and experimental results generalization, empirical and semi-empirical models state, formalized in accordance to experimental investigation results, and on the analysis of these models with the aim of internal and external factors influence detection on complex technical systems technical state parameters.

The totality of those models may be divided in:

– semi-empirical wear and aging models;

– empirical models of mechanical wear;

– structural models of damage accumulation;

– stochastic wear and failure models;

– economic loss and expenditure models during complex technical systems operation [3].

These models are sufficiently common. They are the result of experimental data generalization and are more adapted for experimental data processing and analytical results presentation. Passive and fragmental character, inability to show the most general, fundamental technical system state change pattern in general, in connections with storage, operation and functional article application modes are the disadvantages of these models [3].

That is why to solve the tasks of evaluation, forecasting of technical state change and control the functional state of the aircraft systems, it is necessary to use models, based on other approaches.

IV. MODEL OF AIRCRAFTS SYSTEMS FUNCTION STATE CHANGING

It is well known that any physical system properties may be introduced with the help of equation system, establishing correlation between energy and power flows, taking place between system and environment. The best way to describe such dependencies is to use Hamilton differential equation system, which may be easily reduced to canonical Cauchy's form. That is the common second order differential system. Generally the input coefficients are the dependences of kinetic, dissipative and potential energies correspondently. At the same time these coefficients are the functions of complicated technical system components parameters, i.e. Hamilton equations allow to connect energetic and parametric (informational) evolution processes characteristics, taking place in complex technical systems [3] – [6].

So, integrated dynamic model of complex technical systems may be subdivided in two parts – energetic and informational. Such integrated model should include:

– submodels of complex technical systems components that are generally presented as an ordered hierarchical structure;

– submodel of energy flow through complex technical systems components;

– submodels of virtual parameters removal of complex technical systems components, provided by flowing through them energy flows [4].

The equation of the dynamics of the technical system containing *N* material points are of the form [2]:

$$a_j w_j = F_j^{(e)} + F_j^{(i)} + R_j, \quad (j = 1, 2, \ldots N), \qquad (1)$$

where, $F_j^{(e)}$ are external forces that characterize the interaction of technical systems with the environment; $F_j^{(i)}$ is the internal force; R_j is the constraint reaction; w_j are acceleration vectors; a_j is the mass.

To obtain a closed system of equations to (1) add links equation:

$$f_k(r_1, r_2, \ldots r_N, t) = 0 \quad (k = 1, 2, \ldots N), \qquad (2)$$

where, r is the radius-vector of the masses on the chosen inertial coordinate system O_{xyz}.

The main characteristic of the generalized system (1), (2) is energy. The equation for kinetic (*T*), the potential (*U*) and dissipative (*F*) energy, respectively, are as follows:

$$T = \frac{1}{2}\sum_{j=1}^{n}\sum_{k=1}^{n} a_{jk}\dot{q}_j\dot{q}_k, \qquad U = \frac{1}{2}\sum_{j=1}^{n}\sum_{k=1}^{n} c_{jk}q_j q_k,$$
$$F = \frac{1}{2}\sum_{j=1}^{n}\sum_{k=1}^{n} b_{jk}\dot{q}_j\dot{q}_k, \qquad (3)$$

where, q are generalized coordinates of system; a_{jk} are inertial coefficients; c_{jk} are quasi-elastic coefficients; b_{jk} are dissipative coefficients.

Dynamic changes over time of technical characteristics of the energy system in view of ingredients gives a canonical Hamiltonian system of differential equations of the form [3]:

$$\frac{dq}{dt} = \frac{\partial H}{\partial p}, \qquad \frac{dp}{dt} = -\frac{\partial H}{\partial q} + Q, \qquad (4)$$

where, p is the generalized impulses system; Q are generated forces acting on the system; $H = T + U$ is the Hamilton function, which determines the total energy of the system.

The system of equations (4) by deleting p easily reduced to the canonical form of Cauchy:

$$\ddot{q} = -\frac{1}{A}\left(B\dot{q} + Cq - \sum f\right). \qquad (5)$$

Similar expressions can be easily obtained by systems based on other physical principles: electrical, electromagnetic, electromechanical, etc. In general, expression coefficients A, B and C are coefficients depending on the kinetic and potential energy dissipative respectively. At the same time, these coefficients are functions of the parameters of the technical system, i.e. Hamilton equation (4) can link together energy and parametric (information) characteristics of evolutionary processes that occur in the technical system.

Thus, analysis of equation (5) can make a fundamental conclusion that even most complicated process that occurs in aircraft systems (as complicated technical system) may be represented as a second-order differential equation, which binds together the structural and dynamic energy processes.

This Model of Aircrafts Systems Function State Changing (5) can improve Aircraft reliability program and maintenance planning process for aircraft in the case of service data lack.

V. ENHANCED AIRCRAFT RELIABILITY PROGRAM

Typical Aircraft reliability program is a set of rules and practices developed by the operator and approved by the regulatory authority. It is an event reporting system based on performance values experienced under actual operating conditions. It provides continuous audits of maintenance functions to enhance safety and cost effective maintenance. The program identifies problem areas within in the airplane maintenance process so that corrective action can be taken to fix these problems. The reliability program principals are applicable to all airplane models operated by the operator.

The typical reliability program is a close loop cycle, accomplished by applying the following steps.

1. Identification of performance parameters that reflect airplane reliability.
2. Collecting, analyzing and reporting data gathered from service experience and reflecting airplane reliability.
3. Investigating and identifying the problems.
4. Proposing and applying actions for correction.
5. Monitoring applied actions to ensure that maintenance cycle problems are solved.

Using the Model of Aircrafts Systems Function State Changing when you are facing difficulties with collecting, analyzing and reporting data gathered from service experience and reflecting airplane reliability, allows you to convert Reliability Program close loop cycle as follows (Fig. 3 below). An Enhanced Reliability Program Flow Chart will include the following steps.

1. Identification of performance parameters.
2. Collection of service data.
3. Decision-making if data gathered from service experience is enough for aircraft reliability reflecting.
4. Reporting and analyzing service data or model of navigation systems function condition changing data.
5. Decision-making if performance standards are met.
6. Alert investigation held by engineering technicals and determination of corrective actions.
7. Reliability control board (RCB) approves corrective action.
8. Model of navigation systems function condition changing adjustments.
9. Engineering technicals issue engineering order (EO) to correct problem.
10. Maintenance accomplishes EO on airplane.
11. Cycle repeat itself.

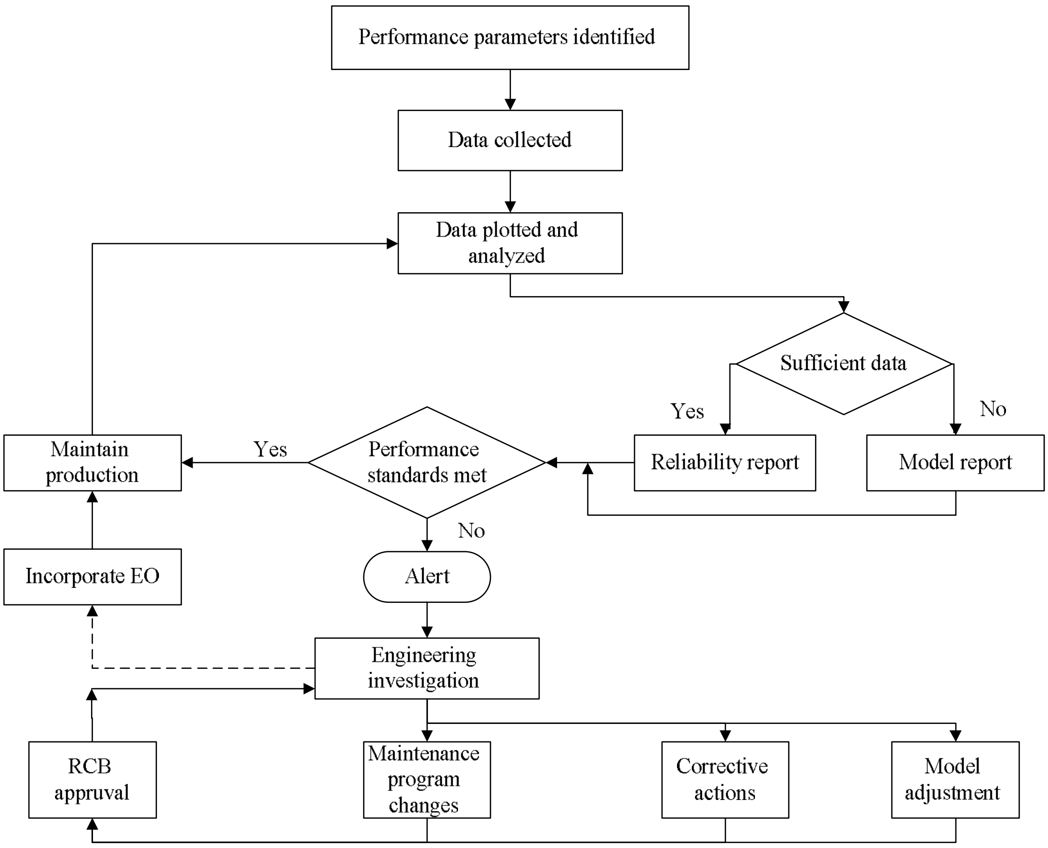

Fig. 3. Enhanced Reliability Program Flow Chart

VI. Results

Present models of wear and aging are applicable only for common systems, they are mostly directed on experimental data processing and do not consider operation conditions peculiarities, that’s why this models are not applicable for determination optimum intervals for line and base maintenance scheduling.

Maintenance intervals appointment on the basis of Model of aircraft systems function state changing in the case, when exists difficulties with collection, analyzing and reporting of data gathered from service experience and reflecting airplane reliability, allows to optimize Reliability Program close loop cycle, and thus increase efficiency and reduce the costs activities for aircraft maintenance.

VII. CONCLUSION

Nowadays in aviation with the aim of maintenance effective planning, there is a problem of aircraft components condition change forecasting, which is the lack of admissible approaches and methods. The legacy models are applicable only for common systems, they are mostly directed on experimental data processing and do not consider separate article exploitation conditions peculiarities.

The solution of the problem – the development of models that allow:

– to take account of unit condition change, caused by either operating time, or service period (operation and storage peculiarities);

– to determine requirements to aircraft maintenance work volume and content, and also.

Existing methods of maintenance intervals determination in practice are facing these main difficulties:

– reliable estimation of failures rate in the case of a small aircraft fleet and / or low flight hours;

– problems with current aircraft system state evaluation, namely: limited failure diagnosis time, lack of equipment necessary for effective concrete element state evaluation, human factor influence on failure detection work results.

The application of principles of maintenance works appointment, based on the prediction of aircraft components technical condition, such as Model of aircraft systems function state changing allows:

– to take account of component state change, caused by either operating time or service period (operation and storage peculiarities);

– to determine requirements to aircraft maintenance work volume and content;

– to improve Reliability Program close loop cycle.

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В. І. Чепіженко, О. О. Тризна. Періодичність призначення технічного обслуговування на основі моделі зміни функціонального стану бортових систем

Представлено новий підхід визначення оптимальних інтервалів для технічного обслуговування повітряних суден. Запропонована модель зміни функціонального стану систем повітряного судна дає можливість надати інформацію для визначення обсягу, складу і виконання інтервалів технічного обслуговування повітряних суден, а також дозволяє враховувати зміни стану компонентів на комплексній основі, викликаних або напрацюванням, або терміном служби, щоб визначити, вимоги до технічного обслуговування повітряних суден, обсяг робіт та їх зміст.

Ключові слова: програма технічного обслуговування; зміна функціонального стану; програма надійності.

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В. И. Чепиженко, А. А. Тризна. Периодичность назначения технического обслуживания на основе модели изменения функционального состояния бортовых систем

Представлен новый подход определения оптимальных интервалов для технического обслуживания воздушных судов. Предлагаемая модель изменения функционального состояния систем воздушного судна дает возможность предоставить информацию для определения объема, состава и выполнения интервалов технического обслуживания воздушных судов, а также позволит учитывать изменения состояния компонентов на комплексной основе, вызванных либо наработкой, или сроком службы, чтобы определить, требования к техническому обслуживанию воздушных судов, объем работ и их содержание.

Ключевые слова: программа технического обслуживания; изменение функционального состояния; программа надежности.

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