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DEVELOPMENT OF A COMPLEX OF FUNCTIONAL MODELS FOR THE PROCESS OF CONTROL AND DIAGNOSTICS OF THE TV3-117 AIRCRAFT ENGINE TECHNICAL STATE AT FLIGHT MODES

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Abstract

Purpose: *The purpose of this article is to develop a set of functional models for control and diagnostics of TV3-117 aircraft engine technical state in flight modes based on IDEF0 notation.* **Methods:** *The article applies the system modeling method at the stage of designing an information system for control and diagnostics of the TV3-117 aircraft engine technical state in flight modes.* **Results:** *An approach is proposed to formalize the processes of information control and diagnostics of the TV3-117 aircraft engine technical state in flight modes based on the methodology of system analysis and IDEF-technologies. A set of functional models for the control and diagnostics of the TV3-117 aircraft engine technical state in flight modes based on IDEF0 technology has been developed, which made it possible to single out the optimization problem and formulate the requirements for its implementation as part of the expert system.* **Discussion:** *The results obtained are applied within the framework of the concept of intellectualizing the process of control and diagnostics of the TV3-117 aircraft engine technical state in flight modes, one of the points of which is the intellectual processing and storage of information about the results of flight tests and operation of the TV3-117 aircraft engine based on the requirements of modern databases and knowledge bases, with the possibility of their integration into modern CASE-technologies.*

Keywords: aircraft engine; IDEF technologies; functional models; IDEF technologies; system analysis

1. Introduction

At present, a modern aviation gas-turbine engine, including TV3-117, and its control systems represent a complex dynamic system. The correct and safe operation of such object requires a constant and continuous analysis of its parameters.

Classification and recognition of the classes of states of a dynamic object are necessary to align the optimal control strategy with the state of the object. The effectiveness of control and diagnostics of aircraft engine state depends significantly on the probability of correct recognition of its technical condition, which directly affects the quality of the engine management systems, which ultimately determines the economy and safety of the aircraft [1].

Research into the development of automated systems for control and diagnosing the technical state of aircraft engines shows the insufficient validity of the use of systems based only on one of the known diagnostic methods, since none of the methods is universal and absolutely reliable. Naturally, such control and diagnostic systems which are built on the basis of a single classifier cannot fully meet the increasing demands for engine diagnostics. There are several directions that determine the increase in efficiency of onboard technologies for control and diagnostics the engine condition [2].

The problem of information control and diagnostics of the technical state of the TV3-117 aircraft engine is not trivial. There can be defined the following main issues that need to be addressed in relation to this problem:

– solving the problems of control and diagnosing the technical state of the aircraft engine TV3-117 in the environment of flight operation of the aircraft;

– development of expert systems in the conditions of distributed databases and knowledge;

– interaction of databases and knowledge at the local and global levels;

– the resources necessary for implementation of control and diagnosis of technical state of the TV3-117 aircraft engine;

– the role of system modeling for solving this problem, etc.

Finding the answer to these and other questions will make it possible to scientifically and efficiently solve the problem of control and diagnosing of the TV3-117 aircraft engine technical state.

2. Analysis of the research and publications

Recently, in the process of creating complex information systems, the role of system modeling has increased significantly. This proves the presence of built-in CASE tools in modern databases (Oracle, Informix, R-Base, etc.), as well as in the most expert systems. However, the presence of these tools as the basic components of system modeling, on the basis of which an application is ultimately built, does not yet mean that they will be used correctly when solving applied problems in a particular field of application. This is explained by the fact that in addition to the general automation of application creation, CASE means, there is still no corresponding methodological support for this process. Therefore, despite the apparent external simplicity, the overall success of system modeling is determined by the experience, knowledge and intuition of the user [3, 4].

Another aspect of this process is the object of research, the complexity of which ultimately determines the nontriviality of its representation (formalization) within the SADT-methodology.

Based on the above mentioned, the application of the methodology of system modeling during the design stage of the intellectual monitoring system allows to rationally justify and formulate the requirements for the future intellectual system, and also develop a system project, identify the full set of functions and determine the interrelation of its individual components for further implementation in the form of a research prototype of expert system of control and diagnostics of the TV3-117 aircraft engine technical state under conditions of flight operation.

3. Problem statement

The formalization of the information portrayal of the TV3-117 aircraft engine within the structure of the SADT methodology and IDEF technology is a separate problem, since the system model ultimately collects all information on the process of control and diagnosing of the aircraft engine TV3-117 technical state in the information "heap". Therefore, the main task solved at this stage is the "transparency" of the representation of the engine and its subsystems in the process of control and diagnosing of the TV3-117 aircraft engine technical state (highlighting the main functions and tasks to be solved), linking information flows with previously defined databases and knowledge structures, as well as its interrelation in the scenarios of working with the expert system and external interfaces with SCADA-systems, PDM and STEP-standards, CALS-technology, other CASE tools.

Thus, based on the system model, at the stage of designing an intelligent system for monitoring and diagnosing of the TV3-117 aircraft engine technical state, using the SADT methodology and IDEF technology [5], the following steps sequence is required:

– develop a functional model in order to identify the full range of functions and tasks to be solved by the expert system;

– develop an information model that determines the logical structure of databases and knowledge, as well as the ways and mechanisms of their management and interaction (substantiation of content, content, management of information flows);

– develop a dynamic model that determines the rules for working with the expert system, which constitute the basis to create an interface (scripts) with the user and determine the dynamics of interaction of the expert system with databases and knowledge.

The final stage of the system modeling is a system project that forms the outlines of the expert system research prototype and a list of requirements that are implemented by it.

Within the course of this work, a complex of functional models is being developed to implement the first step of the task of information control and diagnostics of the TV3-117 aircraft engine technical state at flight modes.

4. Materials and methods of research

The functional model (Fig. 1) is the basis for a meaningful presentation of the system modeling of the process of control and diagnosing of the TV3-117 aircraft engine technical state.

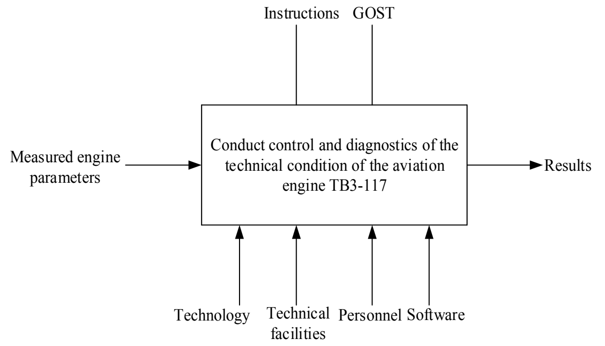


Fig. 1. Functional model of control and diagnostics of the aircraft engine TV3-117 technical state

The process of control and diagnosing of the TV3-117 aircraft engine technical state J is generally characterized by the set of solved problems J_i and their final results $J = \{J_i\}$, where $i \in \left[\overline{1, I}\right]$. Each task at the local level can be described as: $LJ_{ij} = \{kJ_{js}\}$, where $j \in \left[\overline{1, m}\right]$, $s \in \left[\overline{1, k}\right]$, kJ_{js} – subtasks, solved at the local level.

Solving the problems listed above allows us to determine the actual technical state of the TV3-117 aircraft engine and thus to monitor and diagnose its technical condition and control the operation:

$$J_i = \bigcup_{s=1}^{k} kJ_{js}; \quad (1)$$

where $i \in \left[\overline{1, I}\right]$, $j \in \left[\overline{1, m}\right]$, $s \in \left[\overline{1, k}\right]$.

The functional model J on the set theoretic level can be represented as:

$$J = \langle V, W, L, Q, T \rangle; \quad (2)$$

where V – is a set of measured parameters of TV3-117 aircraft engine; W – is a set of normative and directive documents required for high quality and efficient process of control and diagnosing of the TV3-117 aircraft engine technical state; L – is a set of software, hardware and human resources for the process of control and diagnosing of the TV3-117 aircraft engine technical state; Q – is a set of results of technical condition evaluation of TV3-117 aircraft engine; T – is current time of the process of control and diagnostics of the TV3-117 aircraft engine technical state.

Development of an integrated distributed intellectual system, the main function of which is to unite decision support systems within the industry and with the wide range of tasks: testing, refinement, repair, operation, etc. implies the use of CALS technology, SCADA systems, PDM systems, STEP standards and CASE tools. Their complex application based on client / server technologies will allow to carry out the process of control and diagnostics of the TV3-117 aircraft engine technical state efficiently and with high quality.

The technical means used in the process of solving the problems of control and diagnostics of the TV3-117 aircraft engine technical state are the following: network support (Internet); computing equipment with a different configuration and computing platform (from IBM PC to Spartan stations), software (empty and specialized expert envelopes, Matcad, Matlab, Maple, Mathematica, etc. object-oriented programming languages Java, C++, operating systems – Windows, LINUX, UNIX, MacOS, etc., test databases that store engine-engineered information – Oracle, Informix, R-Base, Access, Fox Pro, etc., specialized application packages, designed for the simulation process, etc.

Personalized representation of various units involved in the process of information control and diagnostics of the TV3-117 aircraft engine technical state: operators, database administrators, calculation engineers; engineers-programmers, specialists in aircraft engine repair; specialists in reliability, etc.

The functional model IDEF0 (Fig. 1) is decomposed into a hierarchy of diagrams (Fig. 2), which form the following functional blocks:

1. Record the measurement data of the engine parameters (the parameters of the aircraft engine measured during the test: normalized, calibrated, scaled and recorded in the test database at real-time tempo);

2. Statistic processing of engine data (correlation, factor, regression analysis, etc.), the result of which is the elimination of measurement errors (anomalous values);

3. Control of the engine parameters, during which an assessment is made of its actual state (the engine is defective or not defective);

4. Diagnostics of the engine condition, on the basis of which the presence of a malfunction is

defined and localized, as well as the place of its manifestation;

5. Analysis of the parameters trend and the forecast of the engine technical condition, based on which the tendencies of changes in its parameters are revealed, and short-term, medium-term and long-term forecast of their behavior is made;

6. Taking the decision on the technical condition of the engine, based on which the further operation of the aircraft engine or its removal is decided.

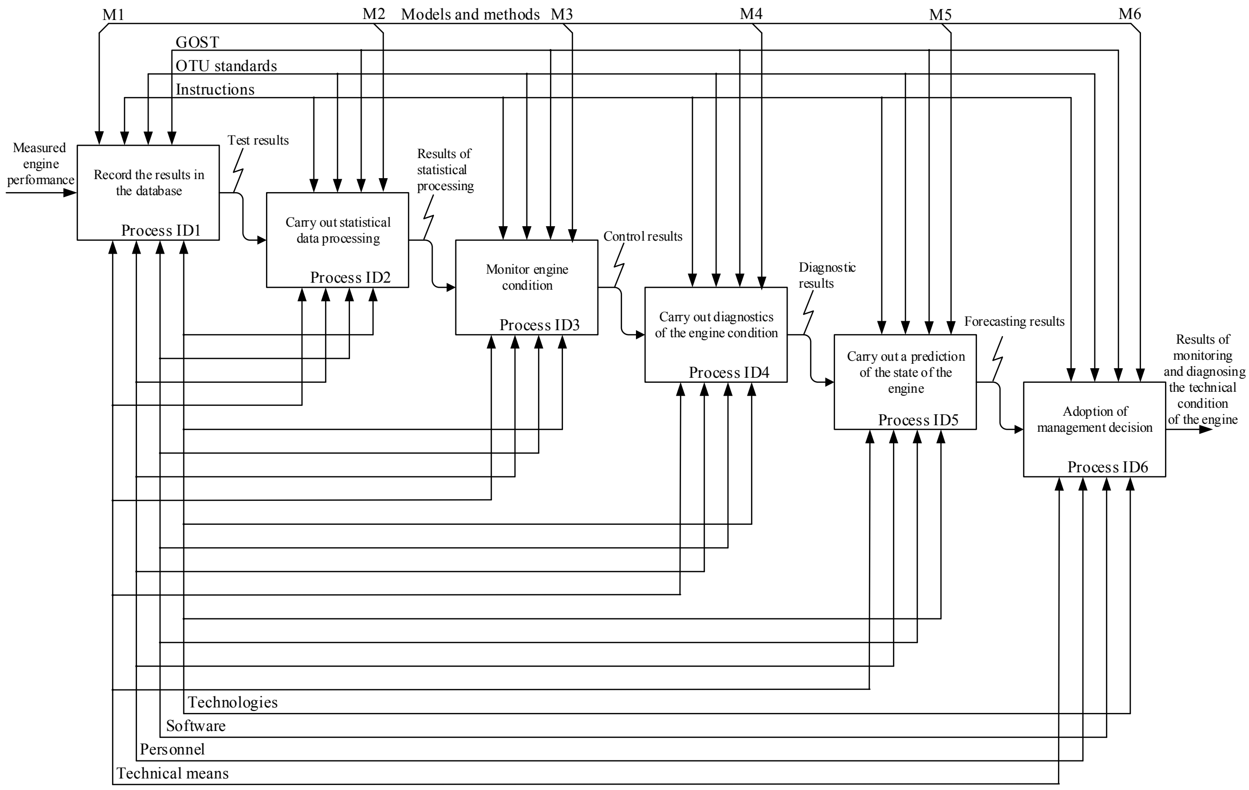


Fig 2. Functional model of the process of control and diagnostics of the aircraft engine TV3-117 technical state

The detailed description of function block 1 in Fig. 2 gives a hierarchy of diagrams (Fig. 3, a), where the following is marked as performed functions:

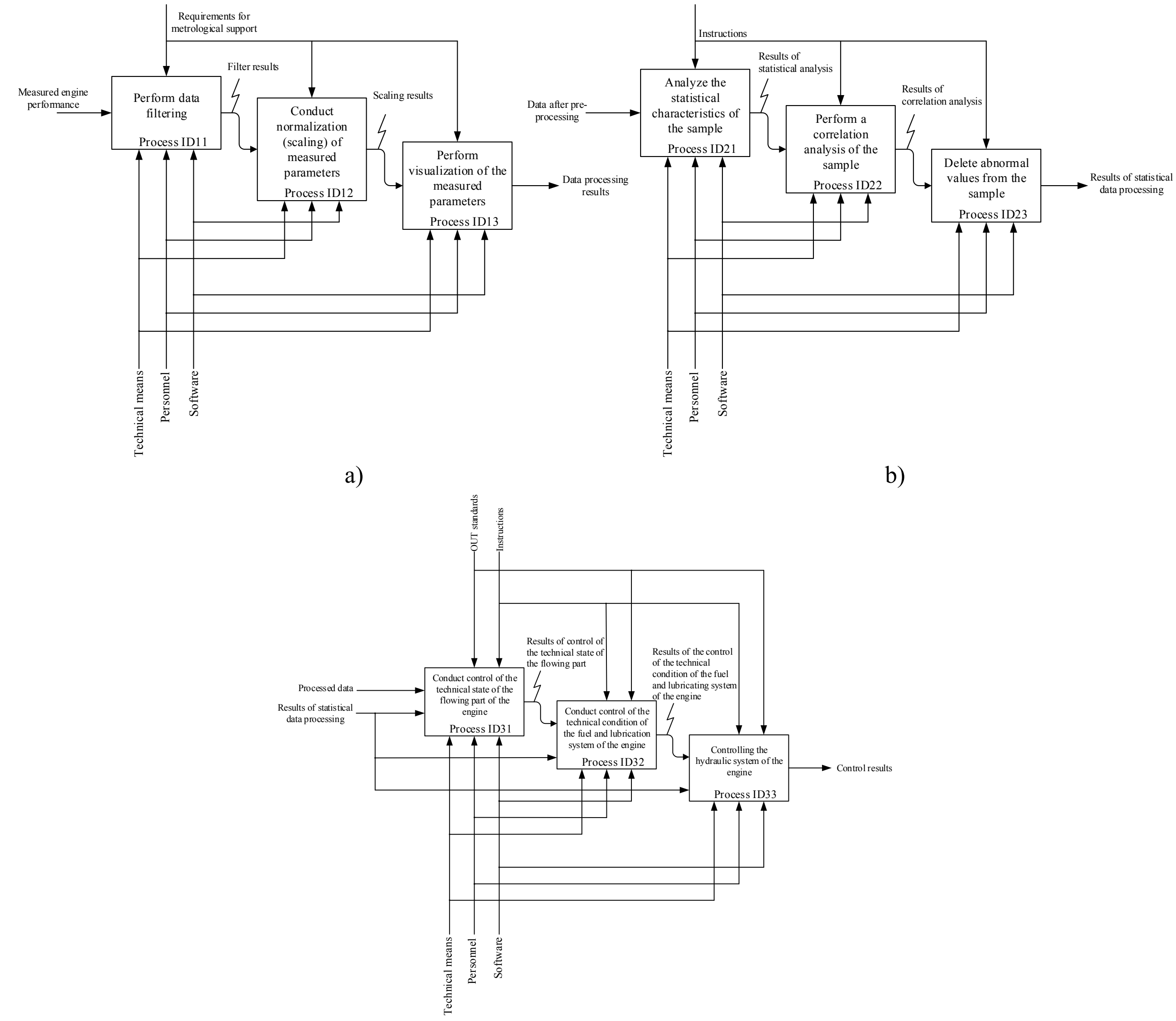
11. Data filtering;

12. Normalization (scaling) of measured engine parameters;

13. Visualization of measured engine parameters (graphical or tabular interpretation of measurement results).

Functional analysis of block 2 in Fig. 2 is shown in Fig. 3, b in the form of a hierarchy of diagrams, where block 21 is a subsystem of the analysis of the statistical characteristics of the sample, the input of which is the data after preprocessing, and its output is the results of statistical analysis. They are the starting material for block 22, which produces a correlation analysis of the sample. The results of this block operation are fed to block 23 – to remove abnormal values from the sample, which "filters" the sample, removing obvious measurement errors.

The analysis of block 3 in Fig. 2 is shown in Fig. 3, c, where the process of monitoring the technical state of the engine is represented by the following functional blocks: 31 – monitoring the technical state of the engine running part (the results of monitoring the thermogas dynamic parameters); 32 – control of the technical condition of the fuel-oil system of the engine (components, assemblies, units of the fuel and oil system); 33 – monitoring the technical condition of the engine hydraulic system (components, assemblies, units of the hydromechanical system of the aircraft engine). In this case, the results of statistical processing are fed to the input of blocks 31–33, and the processed data (the results of their preliminary normalization, calibration and scaling) are fed to the input of block 31.



a) b) c)

Fig. 3. Detailed description of the model function blocks:
a – preprocessing data from the engine test database;
b – statistical processing of data from the engine test database
c – monitoring the technical condition of the engine

A generalized functional model of possible results of processes identifying the technical state of the engine is shown in Fig. 4. At the same time, the functions of their functional model are as follows:

F_1 – function of storing the test results of the engine;

F_2 – function of statistical data processing engine;

F_{2a} – function of statistical processing of test results with correctly measured engine data;

F_{2b} – function of statistical processing of test results with incorrectly measured data;

F_3 – function of control of engine parameters;

F_{3a} – function of control of the technical condition of the engine with correctly measured data and when fulfilling the requirements for statistical processing of test results;

F_{3b} – function of monitoring the technical state of the engine with incorrectly measured data and in case of compliance with the requirements for statistical processing of test results;

F_{3c} – function of monitoring the technical state of the engine with incorrectly measured data and in case of compliance with the requirements for statistical processing of test results;

F_4 – function of diagnosing the technical state of the engine;

F_{4a} – function of diagnosing the technical condition of the engine, with correctly measured data, as well as the requirements of statistical processing of test results and control of the technical condition of the engine;

F_{4b} – function of diagnosing the technical condition of the engine, with incorrectly measured data, as well as in fulfilling the requirements of statistical processing of test results and with full or incomplete control of the technical state of the engine;

F_{4c} – function of diagnosing the technical condition of the engine, with incorrectly measured data, as well as failure to meet the requirements of statistical processing of test results and requirements for controlling the technical state of the engine;

F_5 – function of the prediction of the technical state of the engine;

F_{5a} – function of the prediction of the technical state of the engine, with correctly measured data, as well as in fulfilling the requirements for statistical processing of test results, control and diagnosis of the technical state of the engine;

F_{5b} – function of the prediction of the technical state of the engine, with incorrectly measured data, as well as the requirements of statistical processing of test results, control and diagnosis of the technical state of the engine;

F_{5c} – function of the prediction of the technical condition of the engine, with incorrectly measured data, as well as the failure to meet the requirements of statistical processing of test results, control and diagnosis of the technical state of the engine.

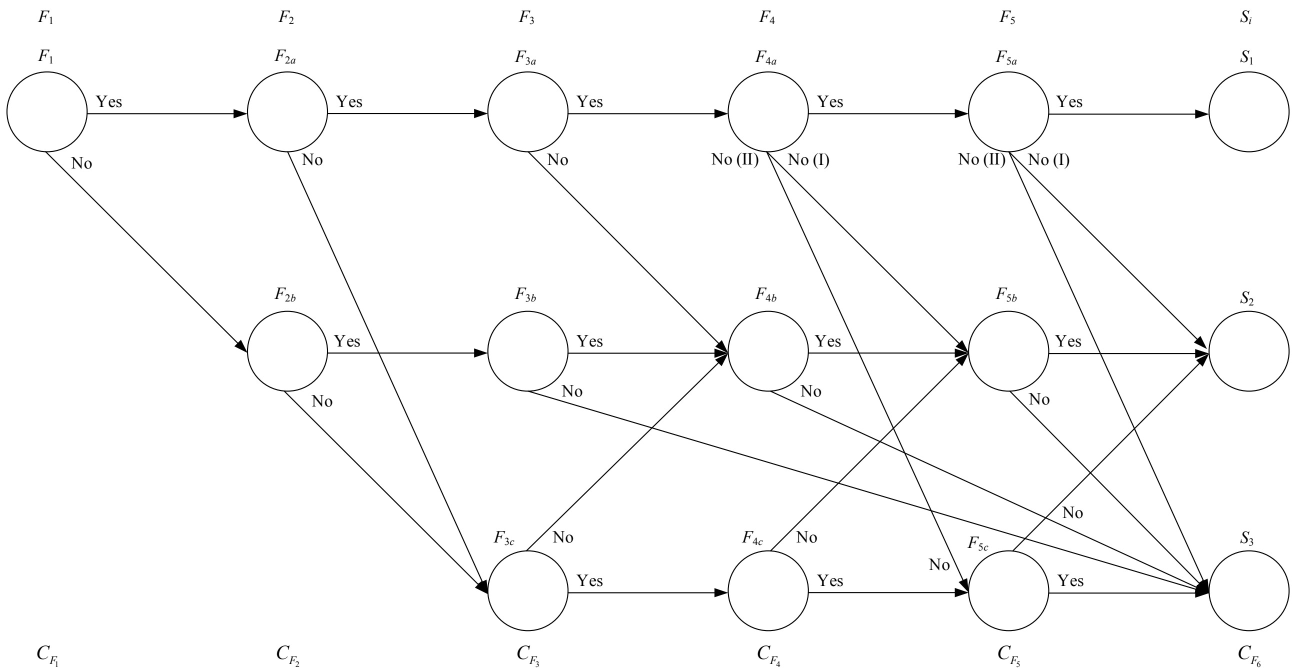


Fig 4. Generalized functional model of possible results of control and diagnostics of the aircraft engine TV3-117 technical state

5. Research results

The process of control and diagnostics of the TV3-117 aircraft engine technical state, within the structure of a generalized functional model, may have the following possible consequences:

S_1 – the engine is working and the solution is "Normal", or the engine is defective and the solution is "Not satisfactory";

S_2 – the engine is working, but the "Not satisfactory" solution is error I;

S_3 – the engine is defective, but the solution "Normal" is type II error.

Errors in decision making have different consequences, and the quality of the diagnostic tasks solution is determined by the system of indicators [6]:

1. The probability of a diagnostic error P_{ij}, $i \neq j$ is the probability of a joint occurrence of two events: the object is in state i, but is considered to be in state j.

2. A posteriori probability of diagnostic error P_{ij}^{A}, $i \neq j$ – probability of finding an object in state i, provided that the result – the object is in the state j.

3. The probability of correct diagnosis P_d – the complete probability that the chosen rule of decision is determined by the state in which the object

actually exists.

Errors of the second kind at the operational stage lead to flight incidents [7, 8] and are characterized by the probability of the P_{II} event, which is essentially deciding to complete the next stage of the life cycle if the goal of the next stage of the life cycle is not achieved. The probability of this event is determined by the probability of simultaneous events of the engines non-compliance with the technical conditions and diagnostic errors of the second kind.

It is assumed that the technical state of the engine is completely controlled, and the calculated relation to determine the probability of errors of the second kind of P_{II} has the form:

$$P_{\text{II}} = (1 - P_{eng})(1 - P_{\partial})^{b}; \tag{3}$$

where P_{eng} – is a probability of compliance of the engine with technical conditions; b – is an indicator of errors of the second type.

The increase in the cost of the life cycle also happens due to errors in the control of its technical state of the first type, which increase the number of engine increments at the design stage, the number of rebates of the engine in production and repair, the number of too early removals of engine, and leads to an increase in the number of tests carried out at all stages life cycle [9].

The probability of removing the engine from operation is determined by the probability of simultaneous occurrence of the event of engine performance and diagnostic errors of the first type:

$$P_{\text{II}} = (1 - P_{\partial})^{a}; \tag{4}$$

where a – is an indicator of errors of the first type.

Thus, errors in diagnosing the technical state at various stages of the engine life cycle lead to the repetition of all test types according to their technology and consequently to the increase of the life cycle cost in general.

Based on the functions described above, it is possible to calculate the overall probability of all results and the total cost of the process of monitoring and diagnosing the technical state of an engine.

The general probability of all possible results of the process of monitoring and diagnosing the technical state of an engine can be calculated by the formula:

$$P(S_i) = \sum_{i,j,l,k} P_i P_j (1 - P_k)(1 - P_l); \tag{5}$$

and the total cost of implementing the functions of monitoring and diagnosing the technical condition by the formula:

$$C_{\Sigma} = \sum_{j} C_{F_j}; \tag{6}$$

where C_{F_j} – is the cost of implementing the function F_j.

The probability of each individual result of the process of monitoring and diagnosing the technical state of the engine can be calculated as follows:

– for event S_1:

$$P(S_1) = P_1 P_{2a} P_{3a} P_{4a} P_{5a}; \tag{7}$$

– for event S_2:

$$\begin{aligned} P(S_2) = {} & P_1 P_{2a}(1 - P_{3a}) P_{4b} P_{5b} + P_1 P_{2a} P_{3a} \times \\ & \times (1 - P_{4a}) P_{5b} + P_1 P_{2a} P_{3a} P_{4a} (1 - P_{5a}) + (1 - P_1) \times \\ & \times P_{2b} P_{3b} P_{4b} P_{5b} + (1 - P_1)(1 - P_{2b}) P_{3c} P_{4b} P_{5b} + P_1 \times \\ & \times (1 - P_{2a}) P_{3c} P_{4b} P_{5b} + P_1 P_{2a} P_{3a} (1 - P_{4a}) P_{5c} + \\ & + (1 - P_1)(1 - P_{2b})(1 - P_{3c}) P_{4c} P_{5b} + (1 - P_1) \times \\ & \times (1 - P_{2\text{б}})(1 - P_{3\text{в}})(1 - P_{4\text{в}})(1 - P_{5\text{в}}); \end{aligned} \tag{8}$$

– for event S_3:

$$\begin{aligned} P(S_3) = {} & P_1 P_{2a} P_{3a} P_{3a} P_{4a} (1 - P_{5a}) + P_1 P_{2a} P_{3a} (1 - P_{4a}) \times \\ & \times (1 - P_{5b}) + P_1 P_{2a} P_{3a} (1 - P_{4a}) P_{5c} + P_1 P_{2a} (1 - P_{3a}) \times \\ & \times (1 - P_{4b}) + P_1 (1 - P_{2a}) P_{3c} P_{4b} (1 - P_{5b}) + P_1 (1 - P_{2a}) \times \\ & \times P_{3c} (1 - P_{4b}) + P_1 (1 - P_{2a})(1 - P_{3c})(1 - P_{4c}) P_{5c} + P_1 \times \\ & \times (1 - P_{2a})(1 - P_{3c}) P_{4c} (1 - P_{5b}) + (1 - P_1) P_{2b} \times \\ & \times (1 - P_{3b}) + (1 - P_1) \times P_{2b} P_{3b} (1 - P_{4b}) + (1 - P_1) P_{2b} \times \\ & \times P_{3b} P_{4b} (1 - P_{5b}) + (1 - P_1)(1 - P_{2b}) P_{3c} (1 - P_{4b}) + \\ & + (1 - P_1) \times (1 - P_{2b}) P_{3c} P_{4c} (1 - P_{5b}) + (1 - P_1) \times \\ & \times (1 - P_{2b})(1 - P_{3c}) P_{4c} (1 - P_{5b}) + (1 - P_1) \times \\ & \times (1 - P_{2b}) P_{3c} (1 - P_{4c}) P_{5c}. \end{aligned} \tag{9}$$

Taking into account that $P(S_i) = f(C_j)$ and quality of monitoring and diagnosing of the technical state of an engine is determined by the probability of the correct implementation of its functions $P_{\Sigma} = \varphi(\{f(C_j)\})$, then the task of monitoring and diagnosing the technical state of an engine can be formulated as an optimization problem: to find such costs C_j, under which the following conditions are true:

$$\begin{cases} \varphi\left(\left\{f\left(C_j\right)\right\}\right) \geq P_{\Sigma add}; \\ C = \sum_j C_j \rightarrow \min; \end{cases} \quad (10)$$

or

$$\begin{cases} C = \sum_j C_j \leq C_{\Sigma add}; \\ \varphi\left(\left\{f\left(C_j\right)\right\}\right) \rightarrow \max; \end{cases} \quad (11)$$

where $P_{\Sigma add}$ – is the given level of quality of monitoring and diagnosing processes; $C_{\Sigma add}$ – is allowable level of expenses for the monitoring and diagnosing process.

Thus, the task of optimizing the process of monitoring and diagnosing the technical condition of an aircraft engine can be stated as (11): with the restrictions on cost, it is necessary to develop an expert system, to provide high quality of the process of monitoring and diagnosing the technical condition of an aircraft engine, that is, to maximize the efficiency of each monitoring and diagnosing function.

6. Conclusions

1. An approach is proposed to formalize the processes of information control and diagnostics of the TV3-117 aircraft engine technical state in flight modes based on the methodology of system analysis and IDEF-technologies.

2. A set of functional models for the control and diagnostics of the TV3-117 aircraft engine technical state in flight modes based on IDEF0 technology has been developed, which made it possible to single out the optimization problem and formulate the requirements for its implementation as part of the expert system.

7. Research prospects

Research of information and dynamic models of control and diagnostics of TV3-117 aircraft engine technical state given in [10]. The complex of functional, informational and dynamic models at the stage of system modeling will allow to implement a system project that forms the contours of a research prototype of an expert system and a list of requirements that implement it.

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Розробка комплексу функціональних моделей для процесу контролю і діагностики технічного стану авіаційного двигуна ТВ3-117 в польотних режимах

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Мета: Метою даної статті є розробка комплексу функціональних моделей контролю і діагностики технічного стану авіаційного двигуна ТВ3-117 в польотних режимах на основі нотації IDEF0. **Методи:** У статті застосовано метод системного моделювання на етапі проектування інформаційної системи контролю та діагностики технічного стану авіаційного двигуна ТВ3-117 в польотних режимах. **Результати:** Запропоновано підхід щодо формалізації процесу контролю і діагностики технічного стану авіаційного двигуна ТВ3-117 на основі методології системного аналізу і IDEF-технологій. Розроблено комплекс функціональних моделей процесу контролю і діагностики авіаційного двигуна на основі технології IDEF0, що дозволило виділити основний спектр завдань і сформулювати вимоги щодо їх реалізації в складі експертної системи контролю і діагностики технічного стану авіаційного двигуна ТВ3-117. **Обговорення:** Отримані результати застосовуються в рамках концепції інтелектуалізації процесу контролю і діагностики технічного стану авіаційного двигуна ТВ3-117 в польотних режимах, одним з пунктів якої є інтелектуальна обробка і зберігання інформації результатів льотних випробувань та експлуатації авіаційного двигуна ТВ3-117 на основі вимог сучасних баз даних і баз знань, з можливістю їх інтеграції в сучасні CASE-технології.

Ключові слова: авіаційний двигун, IDEF-технології, функціональні моделі, IDEF-технологій, системний аналіз

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Разработка комплекса функциональных моделей для процесса контроля и диагностики технического состояния авиационного двигателя ТВ3-117 в полетных режимах

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Цель: Целью данной статьи является разработка комплекса функциональных моделей контроля и диагностики технического состояния авиационного двигателя ТВ3-117 в полетных режимах на основе нотации IDEF0. **Методы:** В статье применен метод системного моделирования на этапе проектирования информационной системы контроля и диагностики технического состояния авиационного двигателя ТВ3-117 в полетных режимах. **Результаты:** Предложен подход к формализации процессов контроля и диагностики технического состояния авиационного двигателя ТВ3-117 на основе методологии системного анализа и IDEF-технологий. Разработан комплекс функциональных моделей процессов контроля и диагностики авиационного двигателя на основе технологии IDEF0, что позволило выделить основной спектр задач и сформулировать требования к их реализации в составе экспертной системы контроля и диагностики технического состояния авиационного двигателя ТВ3-117. **Обсуждение:** Полученные результаты применяются в рамках концепции интеллектуализации процесса контроля и диагностики технического состояния авиационного двигателя ТВ3-117 в полетных режимах, одним из пунктов которой является интеллектуальная обработка и хранение информации о результатах летных испытаний и эксплуатации авиационного двигателя ТВ3-117 на основе требований современных баз данных и баз знаний, с возможностью их интеграции в современные CASE-технологии.

Ключевые слова: авиационный двигатель, IDEF-технологии, функциональные модели, IDEF-технологий, системный анализ

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