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AIRCRAFTS CONTROL RATIONAL INTELLECTUALIZATION

Features of flying vehicles that are functioning under destabilizing influence are reviewed. Basic aspects of the rational control in presence of uncertainty are introduced through the proposed principle of control on diagnosis. Models and methods for intellectualizing diagnosis procedures and ensuring operating capacity of automatic control objects affected by different disturbances are presented. Intellectualization is based on the use of formalized and poorly formalized knowledges of productional type.

Key words: *object of rational control, control principle by diagnosis, destabilizing impact, rational control, diagnosing, recovery, operability, flying vehicle, aircraft.*

Introduction

The growing impact of the technosphere on the biosphere homeostasis processes can cause abnormal phenomena. Environment protection becomes a global objective. In the field of aircraft control systems development, this task is being transformed into a search for the newest, so-called «green» technologies which would allow reduction of using natural both material and energy resources and increase of the level of environmental safety for the aircraft entire life cycle.

Theory and implementation of adaptive control systems have passed through several stages in their development [1-4]. The present days feature is a wide use of models and methods of intellectualization, which are based on the classic control principle known as control on deviation [5-7].

Attempts to implement the intellectual control being under various uncontrollable conditions which would take into account not only exterior disturbances (e.g. noise and interferences) but also internal destabilizing impacts (e.g. malfunction, failures), do not result in effective outcomes. Searching for advanced control principles resulted in forming a control principle with diagnosis [6]. Designing models, methods and tools for aircraft systems of rational control with the diagnosis by means of intellectualizing function of both diagnostics and recovery seems to be an actual problem for the theory as well as practices of resources saving and environmental safety.

1. Flying vehicles features

The reasons violating aircraft operability can be the following.

1. The elastic deformation of the airframe that cause a change of the aerodynamic characteristics.
2. Change of the flight weight because of fuel consumption.
3. The icing of the wings and the tail unit.
4. The defeat by the atmospheric electricity discharge.
5. Control surfaces (elevators, rudders, ailerons, etc…) jamming.
6. Puncture holes in wings, partial loss of the carrying and control surfaces.
7. The traction force change.
8. Solar pressure varying followed by the vehicle attitude change (relative to the center of mass).
9. Gravitational forces of other planets that result in disturbing torques.
10. Partial or complete loss of antennas, solar panels and other retractable elements.
11. Thermal deformation of the hull.
12. Elastic vibrations of retractable parts and a number of other reasons that result in breaking the operability.

To realize the control automation, aircrafts are equipped with actuators and sensor units. There are various factors that affect these elements operability. Among them may be: both external and internal noise and interferences, which disturb signal characteristics, system elements malfunction, so forth.

The noise, interferences and faults cover the set of disturbances, which break nominal operation of the actuator and sensor units and the aircraft as a whole.

2. Control by deviation technique analysis

The control principle by deviation is spread widely due to several indisputable advantages. The First is the ability to detect any destabilizing influence that may occur in the control loop. The second is its capability to compensate a "small" deviation from the pre-defined behavior caused by the destabilizing impact. Thirdly, with the help of appropriate algorithms, the method allows compensation of automatic control object dynamics.

In spite of having such advantages, control on deviation does not allow to fully provide with necessary and sufficient conditions for operability of the aircraft control system if it is under destabilizing impacts. Here, we can highlight the following drawbacks of the control on deviation.

1. The control loop allows compensate the outcomes of destabilizing action rather than parrying avoidable reasons of those impacts.

2. The inherent contradiction of the method is that letting the destabilization to occur at first, and only after that its compensation could follow.

3. During the compensation, operable functional elements work hard and waste power and functional resources. Compensation process makes to work healthy elements in an extensive mode, which requires extra energetical and functional resources.

Control on diagnosis seems to be the further approach, which allows implementing the rational control of aircrafts in uncertain destabilizing conditions [8].

3. Basic concepts of rational control

1. The aircraft control system consists of two interconnected subsystems (Fig. 1). The first one is the object of automatic control (OAC) that implies:

1) the plant (an aircraft);

2) the sensor unit containing measurement sensors along with a means of their diagnosis (faults detecting) and regeneration (isolating and compensating) – DD, RD;

3) the actuator unit, also comprising the tools for both diagnosis and operability restoration.

The second subsystem is a device of automatic control, which, in common, includes a diagnostic module and a control module; the both are based on reliable digital hardware and software highly tolerant to destabilization. Through the bus, digital signals $y(kT_0), u(kT_0)$ and diagnostic devices DD command signals arrange interaction between the subsystems. We take signal $u_3(kT_0)$ as the reference of the system; $v(t)$ is the vector of external forces and torques, acting on the plant; $p(t)$ is the parametric vector, representing the plant spatial (three-dimensional) motion.

2. A variety of states of OAC that has been resulted from various types of destabilizing influence $d_i \in D$, makes it necessary to have a set of redundant resources R, which would allow to recover OAC operability.

3. The rational control of the aircraft that is exposed to an event-uncertain destabilization is based on a thorough diagnosis of avoidable reasons of the fault followed by the real-time flexible operability recovery. Hence, a rational control is the art of achieving the possible in the intelligent control.

4. The object of automatic control is designed so that to ensure its controllability and observability, as

5.

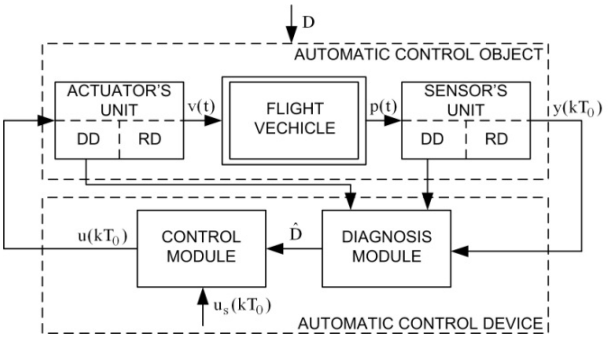

Fig. 1. Block diagram of the automatic rational control system

4. The object of automatic control is designed so that to ensure its controllability and observability, as well as the detectability of a single type of the destabilizing impact; also it is necessary to ensure capability of recovering the operability.

7. Rational control for the object of rational control (ORC) is understood as the result of reasonable combination of formalized and weakly formalized models and methods along with implementing prototyping and bench experimental studies, combining designer's intuition and intelligence.

The objective of the rational control is maintaining required level of OAC operability when it is affected by destabilizing impacts $d_i \in D, i = \overline{1, q}$.

4. Algorithmic support of the fault diagnosis

Knowledge-based systems (KBS) are used for implementing highly intelligent diagnostic algorithms of ORC functional state. For intelligent control, most advanced approaches utilize production rule-based systems. Both knowledge in the form of two-valued predicate equations that are based on ORC diagnostic models and developer heuristic knowledge can be used in KBSs [5]. Such knowledge base employ outcome description based on a dichotomous tree; the mechanism allows forming logic outcomes of the optimal structure that results in the rapid, i.e. real time decision-making while carrying out the diagnosis [7, 8].

Some problems were formulated during a research dedicated to dynamic objects diagnosis. Solving those problems with using instruments of production knowledge-based system (KBS) allowed us to get a means for effective algorithmic support of the diagnosis purposes [9, 10].

Development of the algorithmic support for the process of knowledge-based ORC diagnosing aims to solve the interrelated tasks shown in Fig. 2.

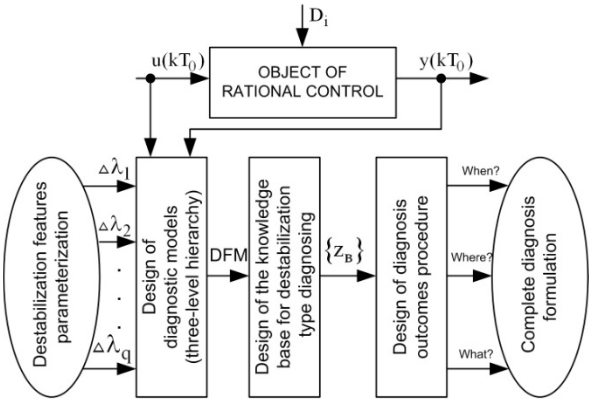

Fig . 2. Tasks package of diagnosis algorithmic support

We use the successive principle of uncertainty removing for step-by-step solving the problem of destabilizing impacts detection, isolation and identification.

To implement the technique, a parameterization of disturbances distinctions is carried out first; it results in forming the ensemble of direct attributes $\triangle\lambda_i$ for every problem. After analyzing cause-effect interrelationships associated with the kind of the disturbance d_i, the following model for a functional relationship between inaccessible (for measurements) direct features $\triangle\lambda_i$ and accessible indirect features $\triangle y_i(kT_0)$ is arranged in a form of linearized discrete state space equations [9, 10]:

$$\begin{aligned}&\triangle x_i(k+1)=A\triangle x_i(k)+[A_i\hat{x}(k)+B_i u(k)]\triangle\lambda_i;\ \triangle x_i(k_0)=\tilde{x}_{i0};\\&\triangle y_i(k)=C\triangle x_i(k)+C_i\hat{x}(k)\triangle\lambda_i;\ i=\overline{1,q},\end{aligned}\qquad(1)$$

where A, B и C – matrices of appropriate dimensionality corresponding to conversion objectives of ORC elements;

$u(k)$ – reference vector, $u(k)\in U^r$;

$\hat{x}(k)$ – state vector estimate, $\hat{x}(k)\in X^n$;

$\triangle x_i(k)=\tilde{x}_i(k)-\tilde{x}(k)$ – state vector for deviation;

$\tilde{x}(k)$ – state vector of the disturbed motion;

A_i, B_i и C_i – sensitivity function matrices associated with the parameter $\triangle\lambda_i$;

$\triangle y_i(k)$ – the vector representing indirect destabilization feature.

With the help of such equations a three-level hierarchy of diagnostic functional models (DFM) is being built and is then used for sequential forming knowledge base production rules aiming to detect, localize and identify the disturbance. The outcomes can be found by solving inverse problems dedicated to finding a direct features estimate $\triangle\hat{\lambda}_i(k)$ through the knowledge of an indirect feature $\triangle y_i(k)$. When having such estimations, the two-valued predicate equations like the following one can be constructed:

$$z_r=S_2\left\{f[\triangle\hat{\lambda}_i(k)-\delta]\right\}=\begin{cases}1,\text{ if } f[\bullet]\geq\delta;\ \forall k\in T;\\0,\text{ if } f[\bullet]<\delta;\ r\in\{d,\ell,i\}.\end{cases}\qquad(2)$$

Set of predicate equations relative to disturbance detection z_d, localization z_ℓ, and identification z_i together with associate data arrays required for solving them form the basis of the data base and knowledge base; the both are implemented for diagnosing RCO component into a depth of disposable fault type $d_i\in D, i=\overline{1,q}$.

Predicate equations are being formed as a structure that should be optimized into a balanced dichotomous tree for the diagnosis outcomes with the help of diagnostic logic models and optimization procedures [11, 12].

5. Algorithmic support of operability recovering procedure

The actuator unit restoration is performed with the help of utilizing RD. By using RD, actuator operability is recovered during the diagnosis. RD in the sensor unit performs a similar function with respect to sensors. Operability recovering of the aircraft (the plant) and entire OAC is performed by the control module that processes associated signals received from the diagnosis module.

The most used recovery tools are the signal and parameter trim (tune), the software and hardware restructuring (reconfiguration). Table 1 illustrates a set of redundant tools to ensure recovering operating efficiency. In the table, fault direct features $\triangle\lambda_i$ specify horizontal rows, and vertical columns determine appropriate tools for faults neutralization.

Every particular RCO get its multifunctional recovery facilities relative to operation capability during the design procedure. They are capable to parry several faults $\triangle\lambda_i$, which are specified by σ_{ij}, elements in the table; the variable takes «1» if the ability to compensate for direct fault effect be present and it takes the value of «0» if such a compensation be impossible.

Parameters ℓ_j, $j=\overline{1,\mu}$, representing the number of ones in a column, are those to specify the rank of the particular recovery tool v_j. Parameter c_i, that is equal to the number of ones in a row specifies the recoverability level. The table is forming so that to meet the following recoverability conditions: $\forall c_i \geq c_T, i = \overline{1,q}$ and $\forall \ell_j \geq \ell_д, i = \overline{1,\mu}$, where c_T notifies a required recoverability level, and $\ell_д$ represents an allowable recovery tool rank.

Table 1

Recovery tool choice

P	Recovery tools				Level
	v_1	v_2	• • •	v_μ	
$\Delta\lambda_1$	σ_{11}	σ_{12}	• • •	$\sigma_{1\mu}$	c_1
$\Delta\lambda_2$	σ_{21}	σ_{22}	• • •	$\sigma_{2\mu}$	c_2
⋮	⋮	⋮	⋮ ⋮ ⋮	⋮	⋮
$\Delta\lambda_q$	σ_{q1}	σ_{q2}	• • •	$\sigma_{q\mu}$	c_q
Rank	ℓ_1	ℓ_2	• • •	ℓ_μ	

In fact, Table 1 represents a dynamic structure of the database for the knowledge-based system aimed at intellectualization of operability recovering process. The production rule relative to the operability recovery is being formed by rows of the table as follows: «If the diagnosis is $\Delta\lambda_i$, then the recovery tools should be those for which $\sigma_{ij} = 1$ ». Choosing the tool for a current process is performed by analyzing the knowledge production base according to scheme: «If the diagnosis is $\Delta\lambda_i$ and, among all the tools, the rank ℓ_j gets the minimum value, then the recovery tool v_j is selected».

For developing operability recovery algorithms that are based on tuning and reconfiguration facilities, one may use Lyapunov's second method that allows derivation of the algorithm from the condition of ensuring the following functional

$$V[\Delta y_i(k)] = \Delta y_i^T(k) Q \Delta y_i(k), \qquad (3)$$

decreasing. This algorithm would ensure the recovery outcome of acceptable performance [13].

Research and experimental verification of the tools dedicated to rational intellectualization have been carried out at the department of aircraft control systems relative to the breadboard model of the orientation system having electrically operated flywheels as the actuators [14]. Completed experimental studies have confirmed practical significance of the theoretical investigation.

Conclusion

Theoretical and experimental research, carried out with the aim to introduce the advanced control on diagnosis, have shown productivity of the chosen approach for rational intellectualization of the aircraft control systems. The proposed models and methods allow designers to form a constructive image of the future control system, which is able to adapt to varying performance conditions with using the profound diagnosis and versatile restoration of operability, at the stage of conceptual design.

Further research require new broad-scale experiments that would utilize next-generation aircraft models subjected to various and changing destabilizing impacts.

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РАЦІОНАЛЬНА ІНТЕЛЕКТУАЛІЗАЦІЯ УПРАВЛІННЯ ЛІТАЛЬНИМИ АПАРАТАМИ

А. С. Кулік

Розглянуто особливості функціонування літальних апаратів при невизначеності дестабілізуючих впливів. Викладено основні положення раціонального управління в умовах невизначеності за допомогою нового принципу управління по діагнозу. Представлені моделі і методи інтелектуалізації процедур автоматичного діагностування та відновлення працездатності об'єктів автоматичного управління в умовах дестабілізуючих впливів. Інтелектуалізація базується на використанні формалізованих і слабоформалізованих знань продукційного типу.

Ключові слова: об'єкт раціонального управління, принцип управління за діагнозом, дестабілізуючий вплив, раціональне управління, діагностування, відновлення, працездатність, літальний апарат.

РАЦИОНАЛЬНАЯ ИНТЕЛЛЕКТУАЛИЗАЦИЯ УПРАВЛЕНИЯ ЛЕТАТЕЛЬНЫМИ АППАРАТАМИ

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Рассмотрены особенности функционирования летательных аппаратов при дестабилизирующих воздействиях. Изложены основные положения рационального управления в условиях неопределенности посредством нового принципа управления по диагнозу. Представлены модели и методы интеллектуализации процедур диагностирования и восстановления работоспособности объектов автоматического управления в условиях дестабилизирующих воздействий. Интеллектуализация базируется на использовании формализованных и слабоформализованных знаний продукционного типа.

Ключевые слова: объект рационального управления, принцип управления по диагнозу, дестабилизирующее воздействие, рациональное управление, диагностирование, восстановление, работоспособность, летательный аппарат.

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