INFORMATION TECHNOLOGIES FOR CREATING ALGORITHMS OF INDICATION OF ABNORMAL SITUATIONS ARISING DURING THE FLIGHT TEST STAGE OF AEROSPACE OBJECTS

INFORMĀCIJAS TEHNOLOĢIJAS AEROKOSMISKO OBJEKTU TESTA LIDOJUMU LAIKĀ RADUŠOS ANOMĀLO SITUĀCIJU INDIKĀCIJAS ALGORITMU RADĪŠANAI

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We consider the problem of aircraft flight safety. The control over the functioning of the onboard equipment and the identification of aircraft stability and controllability characteristics is carried out with the help of the onboard computer. With this purpose, the algorithm for indication of the occurrence of abnormal situations, which is based on the principles of analysis of dynamic characteristics of the controlled object, is developed. It uses a mathematical model based on the basic differential equation, describing the properties of the controlled object. For the formation of such object, the aprioristic information about the object, obtained at the design stage and during the previous flight tests, is used. If the parameter values go out of their allowed ranges, an imbalance occurs in the equation of the model. It is measured quantitatively, and alarm signal is generated in case of the occurrence of an emergency. The algorithm is numerically stable, as it does not use inverse mathematical operations. Therefore, the algorithm is less sensitive to noise, than the algorithms that solve the systems of equations formed from the results of measuring the flight parameters. Creation of the indicator does not need additional equipment as it is realized in software.

Introduction

In the process of flight tests, there is a need for determining the moments of time when unusual properties of the aircraft behavior occur, and for the subsequent study of their physical nature. Thus, there is a problem of creating indicators for the occurrence of such situations. Such indicators are expedient to create on the basis of new information technologies in the form of programs for processing the flight parameters recorded in the onboard computer. It will allow to use the principles of formalization and universality without the application of expensive hardware.

The development of mathematical models for estimating the conditions of technical objects has a great importance during their design and testing. For example, during the development of new kinds of aerospace objects and their testing, the application of mathematical modeling reduces the duration of the test cycle by about 30% and achieves significant reduction of expenses. A large part of the information about the operational condition of technical objects involves their dynamic characteristics. The quantitative information about the parameters that have been realized in objects at their design and manufacturing stages is concentrated in their dynamic parameters. During their further operation, the quantitative estimations of such parameters are means for their further improvement and for ensuring the safety their operation.

The necessity to estimate the dynamic parameters of technical objects is most pronounced at the development and flight-testing of new aircraft designs. Here, the most important is the estimation of such dynamic properties as the aerodynamic properties of the aircraft, the characteristics of its stability and controllability. On the basis of this information, the optimization of analytical expressions that are used to define the rules for the control of the aircraft movement in various modes of flight is made. A special attention is given to the takeoff and landing modes, which are connected to increased risks. In these modes, because of the lower speeds, the efficiency of control considerably changes. The aerodynamic characteristics significantly change because the configuration of the aircraft changes when the landing gear is lowered and the flaps are extended.

The amount of information measured during a single test flight is very large. During the testing of the American B-1 aircraft, it reached about 1600 parameters [12].

There is one common property inherent in all aerospace systems: an extremely low degree of observability of their dynamic characteristics. It is related to the flight restrictions that ensure the safety of flights. For example, the modes in which the oscillatory character of angular deviations of the aircraft would show strongly enough, are excluded. Yet, such processes are necessary for models of identification. Moreover, such movements are eliminated using special dampers in all three channels of aircraft control. The damping is realized by sending the signals from the angular velocity sensors through the feedback loop circuits in the control system. For the identification, only slowly changing signals, taken from the gyroscopic vertical sensors in the channels of trajectory control, are left.

Therefore, to obtain even a minimum of the information suitable for identification of aircraft dynamic characteristics, the flight modes on the edge of its stability and controllability are used. It is because the ground tests, for example, testing aircraft models in a wind tunnel, do not allow to obtain full information. First of all, it concerns the identification of the flutter phenomena arising during flights in a turbulent atmosphere. These phenomena result in metal fatigue stresses, which are very difficult to identify.

The small degree of observability of dynamic parameters leads to mathematical singularities in the algorithms for information processing. It happens in the majority of numerical algorithms related to solving systems of the equations, which are formed from the low-dynamic results of measuring the flight processes. The matrices of such systems are close to being singular, and finding reasonable solutions is not possible.

Thus, there is a problem of developing new information technologies related to the modification of traditional computing algorithms. This problem should be solved using mathematical and software methods, as the possibilities of hardware are already practically exhausted.

In the situations of ill-conditionality, the most valuable information is usually concentrated in the least significant digits of the measurement results. Therefore, round-off errors in calculations will lead to the loss of this information. Because of the consecutive multistage process of calculations, the most part of the useful information, which was stored in the least significant digits, will be lost. The most significant digits disappear as a result of subtraction of nearly equal numbers performed at a late stage. Then division is carried out on these small numbers, which are practically equal to zero, and the results that have no physical meaning are returned. In numerous theoretical works where models of identification are represented in an analytical form, these negative phenomena are not visible. Generally, such models turn out not to be suitable for practical applications, and work in the field of identification has practically stopped.

It is one of principal causes why, in the given scientific project, the problem of introducing new information technologies for practical applications connected with flight tests is being solved.

Essentially new information technologies for the creation of computing algorithms, which have been developed, have allowed to considerably improve their numerical stability. They are based on the application of symbolical combinatory models and on the representation of algorithm in the form of independent fragments, which cannot have a global effect on the result as a whole. Other important feature is that the operations of division have been excluded from computing process and the information about them is stored in an independent block. The mathematical theory of creation of such information technologies has been developed and it was published in other scientific papers.

System of basic differential equations of the model of indication

The system for indication of the aircraft controllability characteristics in longitudinal plane should take into account the effect of external perturbations. During the flight in a turbulent atmosphere, they can have critical values, and they can lead to the occurrence of latent defects in the design. These perturbations do not show themselves in an explicit form, but the information about them can be found in the angular fluctuations of the aircraft pitch that are measured by the gyro horizon.

The information about the aircraft characteristics is contained in the differential equations describing its movement in the longitudinal plane (angular movements relative to the OZ axis), in the lateral plane (angular movements relative to the OY axis) and rotations relative to its longitudinal axis OX. These differential equations have a standard form and are given in many publications, for example, in [13]. Their coefficients are a source of information about the basic aerodynamic characteristics of the aircraft, about the characteristics of its stability and controllability, which can be a useful addition to the information obtained at the previous test stages.

The information about the aircraft characteristics is reflected most fully in the differential equations describing the angular and linear movement of the aircraft. Therefore, the models for indication of the abnormal phenomena at the flight test stage are most expedient to create on their basis. These equations are formalized enough and there is a vast experience in their use at the design stages of various aircraft types. They are given in numerous publications [13, 14] and, consequently, it is expedient to use them in the considered problem.

The recognition of abnormal situations resulting from external perturbations is complicated and, consequently, it is necessary to apply indirect methods for their indication. For this purpose, it is necessary to use a basic system of equations in which the perturbing moments are designated in a direct form [13].

The equation of the moment balance is:

$$M_{az} + M_{DZ} = 0$$
$$M_a = M_a(\alpha, \delta_в, \delta_c, \delta_{ai}, \cdots \delta_{ak}, \bar{x}) \qquad (1)$$

where
α – the pitch angle;
$\delta_в$ – the elevator angle;
δ_c – the stabilizer angle;
δ_{ai} – the values characterizing the positions of flaps, landing gear, and other components affecting the aircraft aerodynamics;
$\bar{x}$ – the relative position of the center of gravity of the aircraft;
$M_{p\,z}$ – the moment depending on the engine thrust D and the coordinates of the center of gravity $(\overline{x_D}\,;\overline{y_D})$.

For the longitudinal balance of the aircraft, usually the elevator angle $\delta_в$ is used.

The sum of the moments (1) is counterbalanced by the moment of forces of inertia, arising at the rotation of the aircraft:

$$I_Z \frac{d^2\vartheta}{dt^2} = -qSb_a(m_z^{\omega z}\frac{d\vartheta}{dt} + m1_z^{\alpha}\frac{d\alpha}{dt} + \\ + m2_z^{\alpha}\Delta\alpha + m^{\delta}{}_z\Delta\delta_B) + M_Z \qquad (2)$$

The relation between the pitch angle and the attack angle is determined by the equation of balance:

$$\frac{GV}{g}\frac{d\theta}{dt} = P\sin\alpha + Y - G\cos\theta \qquad (3)$$

The angle of the flight trajectory is $\theta = \vartheta - \alpha$

As a result of the transformation of these equations, the final differential equation is derived for the change of the pitch angle, which should be included in the mathematical model of the indicator. In this equation, the change of the pitch angle is connected to the moment of the external perturbation ΔM_Z and the angle of the elevator δ. The equation can be written down in the operator form (2) as:

$$(p^2 + a_1 p + a_2)\,p\vartheta = \\ = (T_0 p + 1)(b_M M_Z - b_\delta\,\delta_B) \qquad (4)$$

Using the previous system of the equations, the description of the coefficients of this equation can be found. An advantage of the model is that the coefficients of the equation (4) have a clear physical interpretation and there is aprioristic information about them:

$$a_1 = qS\left[\frac{C_y^{\alpha}}{VG} + \frac{b_a}{I_Z}\left(m_Z^{\omega Z} + m_Z^{\alpha *}\right)\right]$$

$$a_2 = qS\frac{b_a}{I_Z}\left(\frac{qSg}{VG}m_Z^{\omega Z}C_y^{\alpha} + m_Z^{\alpha *}\right)$$

$$T_0 = \frac{VG}{qSgC_y^{\alpha}};$$

$$b_M = \frac{qSgC_y^{\alpha}}{VGI_Z};\; b_\delta = \frac{q^2S^2b_aC_y^{\alpha}m_z^{\delta}g}{VGI_Z} \qquad (5)$$

Therefore, the relations (5) can be used to enter the numerical values of parameters into the model of indication to estimate the characteristics of variability of the equation (4) after substituting in it the values of the signals of the pitch angle and the angle of the elevator δ. Transformations of the equations [12] allow to derive the basic operator describing the control of the aircraft in the longitudinal plane:

$$\vartheta = W_\vartheta^{\delta B}(p)\delta_B + W_\vartheta^{M\,z}(p)M_Z \qquad (6)$$

In it, there can be extracted an operator describing the control of the aircraft using the elevator angle:

$$W_\vartheta^{\delta B}(p) = \frac{K_\vartheta^{\delta B}(T_\theta p + 1)}{p(T^2_{c\vartheta}\,p + 2\xi_{c\vartheta}T_{c\vartheta}p + 1)} \qquad (7)$$

From it follows, that aircraft dynamics with respect to the pitch angle is similar to a consecutive connection of integrating, oscillatory, and forcing parts. At $\xi_{C\vartheta} \geq 1$, the oscillatory part transforms into an aperiodic second order element.

The second operator in (6) characterizes the effect of the influence of perturbing moments during the flight of the aircraft in a turbulent atmosphere:

$$W_\vartheta^{M\,z}(p) = \frac{K_\vartheta^{M\,z}(T_\theta p + 1)}{p(T^2_{c\vartheta}\,p + 2\xi_{c\vartheta}T_{c\vartheta}p + 1)} \qquad (8)$$

$$K_\vartheta^{\delta B} = \frac{b_\delta}{a_2};\; K_{c\vartheta}^{M\,z} = \frac{b_M}{a_2};$$

$$T_{c\vartheta} = 1\big/\sqrt{a_2}\,;\; \xi_{c\vartheta} = a_1\big/2\sqrt{a_2} \qquad (9)$$

The coefficients of the operators reflect the aerodynamic characteristics of the aircraft:

$$K_\vartheta^{\delta B} = \frac{b_\delta}{a_2};\; K_{c\vartheta}^{M\,z} = \frac{b_M}{a_2};$$

$$T_{c\vartheta} = 1\big/\sqrt{a_2}\,;\; \xi_{c\vartheta} = a_1\big/2\sqrt{a_2} \qquad (10)$$

Thus, the mathematical model of indication can be expressed in the operator form, and, from it, it is possible to extract a function that will indicate the signs of an abnormal situation.

Analysis of imbalance function in the model of indication of abnormal situations

Let's consider the structure of model of indication in the operator form. In it, it is necessary to extract an operator describing the influence of external perturbations. In the model of indication, operators, the purpose of which is clear from the way they are described, are used. In case if the values of parameters leave their allowed ranges, an imbalance occurs in the form of a discrepancy between the right and the left parts of the equation:

$$Qw(p)\cdot Y(p) = Rw(p)\cdot X(p) \qquad (11)$$

Here the following operators are used:

$$W(p) = \frac{Rw(p)}{Qw(p)};\quad X(p) = \frac{Rx(p)}{Qx(p)};$$
$$Y(p) = \frac{Rw(p)}{Qw(p)}\cdot\frac{Rx(p)}{Qx(p)} \qquad (12)$$

$$Qw(p) = \prod_{i=1}^{n}(p - pw_i) = \sum_{i=0}^{n} qw_i\ p^i \qquad (13)$$

$$Qx(p) = \prod_{i=1}^{m}(p - px_i) = \sum_{i=0}^{m} qx_i\ p^i \qquad (14)$$

$$Rw(p) = \sum_{i=0}^{Nw} rw_i\ p^i;\ \ Rx(p) = \sum_{i=0}^{Nx} rx_i\ p^i \qquad (15)$$

$$Y(p) = \frac{Rw(p)}{Qw(p)}\cdot\frac{Rx(p)}{Qx(p)} \qquad (16)$$

In the case of any anomalies arising during the test flight, there will be a change of these parameters. It will lead to structural changes of the differential equation (4). The imbalance, arising in this case, can be expressed by function:

$$F(t) \Rightarrow F_Y(t) - F_X(t)$$
$$F_Y(t) = \sum_{i=0}^{n} qw_i \cdot y^{(i)}(t)$$
$$F_X(t) = \sum_{i=0}^{m} rw_i \cdot x^{(i)}(t) \qquad (14)$$

The structure of this function should be taken into account at the formation of algorithms for estimating the characteristics of the aircraft. It has properties that are related to the occurrence of a latent equation of zero balance relative to the components that are generated by the transfer operator of the object. The residual equation will contain the components that related to the input perturbation. We shall prove this condition.

We shall notice, that the basic characteristics of operators are their characteristic polynomials $Qw(p)$ and $Qx(p)$, which contain poles corresponding to the operators *W(p)* and *X(p)*. The characteristic polynomial corresponding to the output *Y(p)* is expressed by a product of these polynomials: $Qwx(p) = Qw(p) \cdot Qx(p)$. Mapping these operators into a function of time is carried out using the operation of their decomposition into sums of partial fractions through the residues corresponding to their poles:

$$Y(p) \Rightarrow y(t)\,;\ y(t) =$$
$$= \sum_{i=1}^{n+m}\left\{\operatorname{Re}z\left(\frac{Rwx(p)}{Qwx(p)}\right)(p = pv_i)\right\}\cdot\exp(pv_i\cdot t) \qquad (18)$$

$$y(t) = \sum_{i=1}^{n}\left\{\operatorname{Re}z\left(\frac{Rwx(p)}{Qwx(p)}\right)(p = pw_i)\right\}\cdot\exp(pw_i\cdot t) +$$
$$+\sum_{i=1}^{m}\left\{\operatorname{Re}z\left(\frac{Rwx(p)}{Qwx(p)}\right)(p = px_i)\right\}\cdot\exp(px_i\cdot t) \qquad (19)$$

The operator of the output signal is defined by a set of poles $\{pv_i\}^{(n+m)}$. In this set, the poles of the object and input influence are:

$$Y(p) = \sum_{i=1}^{n+m}\left\{\operatorname{Re}z\left(\frac{Rwx(p)}{Qwx(p)}\right)(p = pv_i)\right\} / \ (p - pv_i) \qquad (20)$$

So, we have a function:

$$y(t) \Rightarrow \sum_{i=1}^{n+m}\left\{\operatorname{Re}z\left(\frac{Rwx(p)}{Qwx(p)}\right)(p = pv_i)\right\}\cdot\exp(pv_i\cdot t) \qquad (21)$$

This expression defines the left part of the differential equation:

$$F_Y(t) \Rightarrow \sum_{k=0}^{n+m}\cdot\frac{d}{dt}^{(k)}\left\{\sum_{i=1}^{n}\left\{\operatorname{Re}z\left(\frac{Rwx(p)}{Qwx(p)}\right)(p = pv_i)\right\}\{\exp(pv_i t)\cdot qw_k\}\right\} \qquad (22)$$

Changing the order of summation we get:

$$F_Y(t) \Rightarrow \sum_{i=1}^{n+m} \left\{ \left[\operatorname{Re} z \left(\frac{Rwx(p)}{Qwx(p)} \right) (p = pv_i) \right] \cdot \left[\sum_{k=0}^{n} \cdot \frac{d}{dt}^{(k)} \exp(pv_i \cdot t) \cdot qw_k \right] \right\} \quad (23)$$

This function has two components:

$$F_Y(t) = F_{YW}(t) + F_{YX}(t) \quad (24)$$

The function $F_{YW}(t)$ is defined by the poles of the object, and the function $F_{YX}(t)$ is defined by the poles of the input influence. $F_{YW}(t)$ is similar to the impulse response of the object, $F_{YX}(t)$ is similar to the impulse response of the generator of the input signal.

They have the following form:

$$F_{YW}(t) = \sum_{k=0}^{n} qw_k \cdot \frac{d}{dt}^{(k)} \left[\sum_{i=1}^{n} A_i \cdot \exp(pw_i \cdot t) \right]$$
$$A_i = \left\{ \operatorname{Re} z \left(\frac{Rwx(p)}{Qwx(p)} \right) (p = pw_i) \right\} \quad (25)$$

$$F_{YX}(t) = \sum_{k=0}^{m} qw_k \cdot \frac{d}{dt}^{(k)} \left[\sum_{i=1}^{n} B_i \cdot \exp(px_i \cdot t) \right]$$
$$B_i = \left\{ \operatorname{Re} z \left(\frac{Rwx(p)}{Qwx(p)} \right) (p = px_i) \right\} \quad (26)$$

In case if the changes in the structure of the object have not taken place and its parameters correspond to the nominal values, the condition of zero balance at any moment of time is observed for the function:

$$F_{YW}(t) = 0 \quad (27)$$

This condition will hold, if it holds for each component of the process. Therefore, the proof is reduced to the proof of the condition (1) for one component $F_{YW,i}(t)$:

$$F_{YW,i}(t) = \sum_{k=0}^{n} qw_k \cdot \frac{d^{(k)}}{dt} A_i \cdot \exp(pw_i \cdot t) \Rightarrow$$
$$\Rightarrow [A_i \exp(pw_i \cdot t)] \cdot \sum_{k=0}^{n} qw_k \cdot pw_i^{\,k} \quad (28)$$

Let's notice, that the second sum is equal to the value of the characteristic polynomial:

$$Qw(p = pw_i) = \prod_{j=1}^{n} (p - pw_j) \Rightarrow$$
$$\Rightarrow \sum_{i=1}^{n} qw_i \cdot pw_j^i \quad (29)$$

From here follows, that:

$$\sum_{k=0}^{n} qw_k \cdot pw_i^{\,k} = \prod_{j=1}^{n} (pw_i - pw_j) \quad (30)$$

Therefore:

$$\sum_{k=0}^{n} qw_k \cdot pw_i^{\,k} = 0\,; \quad pw_i \in Qw(p) \quad (31)$$

From here the proof of zero balance for the full function follows:

$$F_{YW}(t) = \sum_{i=1}^{n} [A_i \exp(pw_i \cdot t)] \cdot \left[\sum_{k=0}^{n} qw_k \cdot pw_i^{\,k} \right] = 0 \quad (32)$$

However, as the poles of the input signal are not equal to the poles of the object (the case of a resonance is not considered), we have:

$$F_{YX}(t) = \sum_{i=1}^{m} [B_i \exp(dx_i \cdot t)] \cdot \left[\sum_{k=0}^{n} qw_k \cdot px_i^{\,k} \right] \neq 0$$
$$px_i \notin Qw(p) \quad (33)$$

Hence:

$$F_Y(t) = \sum_{i=1}^{m} [B_i \exp(dx_i \cdot t)] \cdot \left[\sum_{k=0}^{n} qw_k \cdot px_i^{\,k} \right] \quad (34)$$

Let's notice, that, in the majority of classical models of identification, the requirement of having a zero balance of the basic differential equation is not taken into account. Therefore, the estimations of object parameters will contain methodical mistakes. For example, such mistakes contain models in the form:

$$\beta_1 y(t_i - 1) + \cdots + \beta_m y(t_i - m) = y(t_i)$$
$$t_i \in (t_0 \cdots t_N) \quad (35)$$

$$\beta_1 y(t_i - 1) + \cdots + \beta_m y(t_i - m) -$$
$$- \alpha_1 x(t_i - 1 - k) - - \cdots - \alpha_m x(t_i - m) = y(t_i)$$
$$t_i \in (t_0 \cdots t_N) \quad (36)$$

Their generating operator is a discrete operator that is found using the operator of discrete transform $\varphi Z(T)$:

$$D(z) = \varphi Z(T) * W(p) \Rightarrow \frac{A(z)}{B(z)} =$$
$$= \frac{\alpha_m z^m + \alpha_{m-1} z^{m-1} + \ldots + \alpha_1 z + \alpha_0}{z^n + \beta_{n-1} z^{n-1} + \beta_{n-2} z^{n-2} + \ldots + \beta_1 z + \beta_0} \quad (37)$$

For the same reason, methodical errors arise in models, in which a formal operator $H(q,\theta)$ is artificially introduced, using which they want not only to calculate the estimations of object parameters, but also an estimation of the characteristics of the additive noise leaking into the output signal [11]:

$$y(t) = G(q,\theta)u(t) + H(q,\theta)e(t) \quad (38)$$

Analysis of sensitivity of imbalance function to variations of parameters of the basic differential equation

For reliable indication of the occurrence of abnormal situation in the controlled object, the equation of imbalance of the differential equation relative to the nominal values of its coefficients is used. The vector of nominal coefficients is determined under the aprioristic information about the object, which is gathered at the design stage and also during its operation. In case of a normal condition of object, the imbalance function (14) will have a small value. Its value depends on the values of variations of the parameters of object's transfer function. The imbalance equation can be written down in the operator form:

$$Bal(p)^{\langle j\rangle} := \left(Y(p)\cdot Qw1^{\langle j\rangle} - X(p)\cdot rw1^{\langle j\rangle}\right) \quad (39)$$

Forming it on a set of time points, it is possible to determine the fact of occurrence of an abnormal situation from the RMS of the deviation of the right part of the equation from the left part at a set of time units *(jT)*:

$$Bal(p)^{\langle j\rangle} := \left(Lew(p)^{\langle j\rangle} - Prav(p)^{\langle j\rangle}\right) \quad (40)$$

Let's consider the operators of the transfer function of an 4th-order object for a given kind of input influence:

$$W(p) := \frac{Rw(p)}{Qw(p)} \qquad X(p) := \frac{Rx(p)}{Qx(p)}$$

$$Y(p) := \frac{Rw(p)}{Qw(p)}\cdot\frac{Rx(p)}{Qx(p)} \quad (41)$$

Let the nominal parameters of operators be given by polynomials:

$$Rw(p) := 9 + 10\cdot p + 11\cdot p^2;$$

$$Rx(p) := 12 + 13\cdot p^2 \quad (42)$$

$$Qx(p) := 336 + 146\cdot p + 21\cdot p^2 + p^3;$$

$$Qw(p) := 120 + 154\cdot p^2 + 71\cdot p^3 + 14\cdot p^4 + p^5 \quad (43)$$

Now, let's create abnormal situations with the following variations of the parameters of operator *W(p)*:

$$Rw1^{\langle i\rangle} = Rw^{\langle i\rangle}\cdot(1+0.1\cdot i); \quad i\in(0\cdots 6)$$

$$Ry1 := \begin{pmatrix} 108 & 118.8 & 129.6 & 140.4 & 151.2 & 162 & 172.8 \\ 237 & 260.7 & 284.4 & 308.1 & 331.8 & 355.5 & 379.2 \\ 262 & 288.2 & 314.4 & 340.6 & 366.8 & 393 & 419.2 \\ 143 & 157.3 & 171.6 & 185.9 & 200.2 & 214.5 & 228.8 \end{pmatrix} \quad (44)$$

$$Qw := \begin{pmatrix} 120 & 175.692 & 248.832 & 342.732 & 460.992 & 607.5 & 786.432 \\ 154 & 204.974 & 266.112 & 338.338 & 422.576 & 519.75 & 630.784 \\ 71 & 85.91 & 102.24 & 119.99 & 139.16 & 159.75 & 181.76 \\ 14 & 15.4 & 16.8 & 18.2 & 19.6 & 21 & 22.4 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 \end{pmatrix} \quad (45)$$

Here the vector of nominal parameters is given in the first column of the table. In the others columns, the deviation the parameters happens with the step of 10%. For each variant, at the output of the object there should be a signal corresponding to a certain variation of parameters. Signals are calculated with use of operation of decomposition:

$$Y(p) = \sum_{i=1}^{4}\frac{Aw_i}{p - pw_i} + \sum_{i=1}^{3}\frac{Ax_i}{p - px_i} \quad (46)$$

To this decomposition the following function in time domain corresponds:

$$y(t) = \sum_{i=1}^{4} Aw_i\cdot\exp(pw_i\cdot t) + $$

$$+\sum_{i=1}^{4} Ax_i\cdot\exp(px_i\cdot t) \quad (47)$$

The variations of parameters result in a variation of weight factors of decomposition. It is visible from the Table 1. It leads to a change in the character of dynamic processes shown in the Table 2. From its analysis follows, that even small deviations of parameters by 10% lead to substantial differences between the columns. For each variant, using the formula (34), we find the values of derivatives for formation the imbalance function at the time points. For a variant of normal condition of object, the values of derivatives from the 0th up to the 4th orders are shown in Table 3. Using this method, we the find the values of imbalance function for each variant that are show in Table 4.

Table 1. Decomposition coefficients of the output signal

$$
RzlY := \begin{pmatrix}
-0.642 & -0.87 & -1.159 & -1.527 & -1.996 & -2.6 & -3.382 \\
17.55 & 26.05 & 38.891 & 58.902 & 91.378 & 147.029 & 249.869 \\
-120.833 & -221.947 & -444.212 & -1.038\times 10^{3} & -3.439\times 10^{3} & -722.857 & 1.432\times 10^{4} \\
344.5 & 1.253\times 10^{3} & 411.784 & -7.793\times 10^{3} & -1.338\times 10^{3} & 9.335\times 10^{3} & 1.185\times 10^{3} \\
-474.375 & -1.526\times 10^{3} & 411.784 & 5.182\times 10^{3} & 6.918\times 10^{3} & -5.06\times 10^{3} & -6.777\times 10^{3} \\
314.683 & 599.708 & 1.317\times 10^{3} & 3.999\times 10^{3} & -1.606\times 10^{3} & -1.133\times 10^{4} & -1.205\times 10^{4} \\
-80.883 & -130.553 & -221.576 & -407.078 & -859.59 & -2.496\times 10^{3} & 1.896\times 10^{3}
\end{pmatrix}
$$

Table 2. Object’s output signals for different operating modes

$$
y := \begin{pmatrix}
-8.527\times 10^{-14} & 0 & 1.512\times 10^{3} & -1.478\times 10^{-12} & -234.263 & -1.013\times 10^{4} & -1.17\times 10^{3} \\
1.614\times 10^{-4} & 1.763\times 10^{-4} & 1.318\times 10^{3} & 2.054\times 10^{-4} & -147.827 & -8.937\times 10^{3} & -1.029\times 10^{3} \\
1.091\times 10^{-3} & 1.183\times 10^{-3} & 1.148\times 10^{3} & 1.358\times 10^{-3} & -79.976 & -7.887\times 10^{3} & -904.794 \\
3.108\times 10^{-3} & 3.344\times 10^{-3} & 1\times 10^{3} & 3.78\times 10^{-3} & -27.329 & -6.96\times 10^{3} & -794.472 \\
6.206\times 10^{-3} & 6.623\times 10^{-3} & 870.678 & 7.367\times 10^{-3} & 12.929 & -6.141\times 10^{3} & -696.991 \\
0.01 & 0.011 & 757.764 & 0.012 & 43.137 & -5.419\times 10^{3} & -610.967 \\
0.015 & 0.015 & 659.254 & 0.017 & 65.233 & -4.782\times 10^{3} & -535.142
\end{pmatrix}
$$

Table 3. Changes of the signal and its derivatives depending on time for normal condition of the object

$$
\begin{pmatrix}
-8.5265\times 10^{-14} & 6.8212\times 10^{-13} & -5.457\times 10^{-12} & 143 & -4.743\times 10^{3} \\
1.6141\times 10^{-4} & 0.0229 & 2.0267 & 65.0067 & -3.1391\times 10^{3} \\
1.0914\times 10^{-3} & 0.0726 & 2.7832 & 14.528 & -1.9722\times 10^{3} \\
3.1083\times 10^{-3} & 0.1289 & 2.7397 & -16.0989 & -1.1387\times 10^{3} \\
6.2058\times 10^{-3} & 0.1792 & 2.2324 & -32.6995 & -557.597 \\
0.0102 & 0.2167 & 1.4958 & -39.6586 & -165.2971 \\
0.0148 & 0.2385 & 0.6884 & -40.2391 & 87.4682
\end{pmatrix}
$$

Table 4. The values of the imbalance function for different operating modes

$$
\begin{pmatrix}
2.7285\times 10^{-11} & 1.0737\times 10^{3} & 1.3618\times 10^{3} & 1.26\times 10^{3} & 1.0945\times 10^{3} & 1.1226\times 10^{3} & 1.532\times 10^{3} \\
4.0927\times 10^{-11} & 875.2498 & 1.0419\times 10^{3} & 856.9516 & 614.9547 & 548.3727 & 827.4002 \\
6.9804\times 10^{-11} & 716.5692 & 793.1594 & 551.6887 & 258.1865 & 122.7939 & 299.7634 \\
-7.9581\times 10^{-11} & 589.8491 & 600.9407 & 323.639 & -1.8751 & -185.6039 & -87.7332 \\
-9.22\times 10^{-11} & 488.725 & 453.4974 & 156.2057 & -186.3144 & -402.2807 & -364.9641 \\
1.1596\times 10^{-10} & 408.0473 & 341.3303 & 36.0348 & -312.0941 & -547.7515 & -556.0733 \\
6.7018\times 10^{-11} & 343.6594 & 256.8049 & -47.5807 & -392.8087 & -638.4844 & -680.507
\end{pmatrix}
$$

The deviations of values relative to the first column, where the imbalance corresponding to the nominal parameters is equal to zero, are significant. Therefore, the stated method can be realized in the software of aircraft onboard computer for indicating the fact that some parameter has gone out of its allowed range.

The carried out analysis shows the high sensitivity of the method to the variations of object parameters relative to the nominal values.

Conclusions

As the flight tests of new aircraft designs are connected to significant risks, it is necessary to apply special indicators of occurrence of abnormal situations. Application of modes of flight that are carried out on the edge of losing the stability and controllability of aircraft, demands the application of indicators based on an estimation of dynamic characteristics of the aircraft and its equipment. For this purpose, new information technologies will be applied to create algorithms and software for systems of indication implemented in the onboard computer. The problem is solved on the basis of mathematical model that takes into account the physical properties of the controlled object. Therefore, in the models of indication, the basic differential equations of the controlled object are applied. Their description is made on the basis of the aprioristic information obtained at the design stage and during the previous test flights. It is offered, instead of solving these equations directly, to use indirect estimations of their properties on the basis of measurements of the signals by the aircraft sensors. Such approach allows to preserve the validity of the algorithms. The direct solution of the equations cannot be used in conditions of bad observability of dynamic properties of objects, which is inherent in all aerospace objects. This property arises because of the flight restrictions that are applied to ensure the safety of flights.

The developed function describing the imbalance in the differential equation allows to obtain such estimations. The indicator of abnormal situations is realized using the software of the onboard computer and, consequently, it does not require the use of additional equipment.

References

1. Grundspenkis J., Burov G. Display of information in associative models of acceptance of the decisions // 41st issue of series: Boundary field problems and computer simulation. – Riga: Riga Technical University. 1999. –pp. 114-125.
2. Grundspenkis J., Burov G. Topological associative models of signals processing // Scientific proceedings of Riga Technical University. Series-Computer science. Applied computer systems. – 3rd thematic issue (2000), p. 46.
3. Burov G., Grundspenkis J. Topological properties of associative algorithms of identification and forecasting // Proceedings of the second international conference Simulation, Gaming, Training and Business Process Reengineering in Operations. – Riga, 2000. – pp. 145-149.
4. Grundspenkis J., Burov G. The analysis of topological characteristics of information identification models // Scientific proceedings of Riga Technical University. Series-Computer science. Applied computer systems. – 4st thematic issue (2001).
5. Burov G. Symbolical combinatory model of parallel algorithm of identification using the method of least squares // 50th issue of series: Boundary field problems and computer simulation. – Riga: Riga Technical University, 2008.
6. Burov G. Numerically stable symbolical combinatory model of polynomial approximation for problems of identification and imitation modeling // 50th issue of series: Boundary field problems and computer simulation. – Riga: Riga Technical University, 2008.
7. Burov G. Models for decoding the results of computer control of analog technical objects // 49th issue of series: Boundary field problems and computer simulation. – Riga: Riga Technical University, 2007.
8. Burov G. Principles of formation of parallel algorithms of the information processing in dynamic objects // Scientific proceedings of Riga Technical University. Series: Computer science. Technologies of computer control. – 3rd thematic issue (2003).
9. Burov G. Parallel architecture of algorithms of dynamic objects identification // Scientific proceedings of Riga Technical University. Series: Computer science. Technologies of computer control. – 3rd thematic issue (2003).
10. Burov G. Combinatorial methods of formation of parallel algorithms of the signals processing. 45th issue of series: Boundary field problems and computer simulation. – Riga: Riga Technical University, 2003.
11. Льюнг Л. Идентификация систем. Теория для пользователя. – М.: Наука, 1991.
12. Ярмарков Р.Г. Летные испытания первых опытных образцов самолетов. – М.: Машиностроение, 1987.
13. Автоматизированное управление самолетами и вертолетами / Под. ред. С.М. Федорова. – М.: Транспорт, 1977.

14. Пашковский И.М. Устойчивость и управляемость самолетов. – М.: Машиностроение, 1975.
15. Махоньков Ю.Е. и другие. Автоматизированная обработка результатов измерений при летных испытаниях. – М.: Машиностроение, 1983.
16. Знаменская А.М. и другие. Информационно - измерительные системы для летных испытаний самолетов и вертолетов. – М.: Машиностроение, 1984.
17. Elson B.M. Boeing gains real-time data // Aviation week and space technology. – Vol.118, No.3, (1983).

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J.Grundspeņķis, G.Burovs. Informācijas tehnoloģijas aerokosmisko objektu testa lidojumu laikā radušos anomālo situāciju indikācijas algoritmu radīšanai

Rakstā apskatīta lidojumu drošības problēma. Lidmašīnas aprīkojuma funkcionēšanas kontrole un lidmašīnas stabilitātes un vadāmības raksturojumu identifikācija tiek veikta izmantojot borta datoru. Šim nolūkam ir izstrādās algoritms anomālu situāciju rašanās indikācijai, kas pamatojas uz novērojumu objekta dinamisko raksturojumu analīzi. Tajā ir izmantots matemātiskais modelis, kas balstās uz bāzes diferenciālvienādojumu, kas apraksta novērojumu objekta īpašības. Tā veidošanai izmanto aprioro informāciju par objektu, kas iegūta tā konstrukcijas izstrādāšanas un iepriekšējo izmēģinājumu laikā. Parametru vērtībām izejot ārpus pieļaujamajām robežām modeļa vienādojumā rodas nelīdzsvarotība. Tā tiek kvantitatīvi izmērīts un, ja ir radusies avārijas situācija, tiek dots trauksmes signāls. Algoritms ir skaitliski stabils, jo tajā netiek izmantotas inversās matemātiskās operācijas. Tādēļ algoritms ir mazāk jutīgs pret trokšņiem, nekā algoritmi, kas paredzēti vienādojumu sistēmu, kas veidotas no lidojuma parametru mērījumu rezultātiem, risināšanai. Indikatora izmantošanai nav nepieciešams papildus aprīkojums, jo tas ir realizēts ar programmatūras līdzekļiem.

Я. Грундспенкис, Г. Буров. Информационные технологии создания алгоритмов индикации аномальных ситуаций на этапе летных испытаний аэрокосмических объектов

Рассматривается проблема обеспечения безопасности полетов самолетов. Контроль за функционированием бортового оборудования и идентификация характеристик устойчивости и управляемости самолета осуществляется с помощью бортовой ЦВМ. С этой целью разрабатывается алгоритм индикации возникновения аномальных ситуаций, который основан на принципах анализа динамических характеристик объекта наблюдения. В нем используется математическая модель, основанная на базовом дифференциальном уравнении, описывающем свойства объекта наблюдения. Для ее формирования используется априорная информация об объекте, полученная на этапе конструкторских разработок и на предыдущих этапах летных испытаний. При выходе параметров за допустимые пределы возникает дисбаланс в уравнении модели. Он измеряется количественно и выдаются сигнал тревоги в случае возникновения аварийной ситуации. Алгоритм обладает вычислительной устойчивостью, поскольку в нем не используются математические операции обратного типа. Поэтому алгоритм меньше чувствителен к шумам, чем алгоритмы предназначенные для решения систем уравнений, формируемых по результатам измерений полетных параметров. Для создания индикатора не требуется дополнительное оборудование, поскольку он реализуется программными средствами.