# INFORMATION TECHNOLOGIES FOR INCREASING THE USABILITY OF ALGORITHMS USED DURING AIRCRAFT FLIGHT TEST STAGE

# INFORMĀCIJAS TEHNOLOĢIJAS LIDMAŠĪNU TESTA LIDOJUMIEM PAREDZĒTO ALGORITMU VEIKTSPĒJAS UZLABOŠANAI

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***The problem of creating efficient algorithms for estimating the characteristics of aircraft and its equipment at the flight test stage is considered. The problem is solved with the application of identification models suitable for processing the dynamic processes measured by aircraft sensors. The traditional models based on statistical principles with the application of regression analysis methods are not good enough. The requirements of flight safety do not allow to create modes of flight, in which it would be possible to completely obtain the observable information about the dynamic parameters of the object. For this reason, the systems of equations, formed from the results of signal measurements, are ill-conditioned and the errors in their solutions are sensitive to noise. Such algorithms yield erroneous results and are unusable. Besides, the usability of algorithms depends on their structure. Using Toeplitz matrices as the matrices of measurement results in models of identification is inadmissible, as the returned results are erroneous. The suggested algorithms are based on the use of the aprioristic information about the objects. Information technologies for their creation are considered from the positions of mapping the dynamic information into the circuits of calculation spaces. It is proved, that in the region of operating conditions the object can be identified with the accuracy that is sufficient for practical applications. The specified approach allows to optimize the characteristics algorithm usability. On their basis, much more information about the characteristics of the aircraft and its equipment can be gathered. It allows to reduce the duration of the flight test cycle and to reduce the expenses.***

## Introduction

At the flight test stage, there is an opportunity to gather the maximal amount of information about the dynamic characteristics of aerospace objects. Therefore, there is a problem of improving the usability of algorithms for processing the flight information. Situations where results are erroneous should be allowed at the flight test stage. But the necessity of using mathematical modelling during the test period still remains. Practice has shown, that by using it, the duration of the flight test cycle can be reduced by 30%, and also the expenses can be considerably lower. The algorithms and software of the onboard computer, used in the identification models, must be continuously improved using the newest information technologies. It is so, because the amounts of the flight information increase with the advancement of aircraft evolution. So, for example, at the tests of the American aircraft B-1, the amount of information gathered for a single flight was about 1600 parameters [8, 9].

It demands increasing the performance of the onboard computer, which can be achieved by using parallel computers. But, for this purpose, it is necessary to create modified algorithms with a parallel structure. First of all, it applies to the basic algorithms for solving the systems of equations. Research results described in [3, 4, 5] have shown, that this problem can be solved due to the use of new information technologies based using of symbolical combinatory computing models.

Processing the results of flight tests in the control and measuring systems with the use of accompanying mathematical models allows to gather additional information about the characteristics of aerospace object stability and controllability. It allows to reduce the necessary number of test flights and to lower the expenses related to the development of new aircraft designs.

Introduction of new information technologies allows the computers of the onboard measurements systems to use mathematical modeling for performing the optimization of the rules of control for various predetermined modes of flight. In this case, it is necessary to identify the characteristics of the controlled objects and to include them in the mathematical model.

However, there still are difficulties in ensuring the usability of algorithms. They are related to the ill-conditionality of the dynamic characteristics, which is specific to all aerospace objects. These characteristics cannot manifest themselves because of the flight restrictions on the conditions that ensure the flight safety. In such conditions, the usability of algorithms can vary in an unpredictable way because of the occurrence of singular situations during the solving of ill-conditioned equation systems. Therefore, there is a practical problem of development and introduction of new information technologies for increasing the usability of algorithms for signal processing during the flight test stage of aerospace objects.

## Formation of models of signal processing using the principles of information monitoring

The reasons why computing algorithms are unusable, are substantially related to the character of mathematical models used for processing the measurement information. The majority of traditional models are formed on the statistical principles requiring the normal law of noise distribution. For these models, the basic form of description is used, in which the influence of noise is introduced using the operator method:

$$A(z)y(t) = B(z)\cdot x(t) + C(z)e(t) \qquad (1)$$

It is believed, that such models have an important value in applications, as such models allow to use the methods of regression analysis. However, they are inapplicable, because the operator of noise completely distorts the structure of the solution of (1).

One of the variants of a circuit for processing the information in identification models can be presented as consecutive linking of mapping operators of the calculation data and their transformation from one form into another. Since the onboard sensors are not adapted for measurement of derivatives, the information on them usually is found in the form of final differences of various orders. They are used for formation of systems of difference equations:

$$\sum_{i=0}^{m} a_i \cdot x\left[t-(m+k-i)T\right] - \sum_{j=0}^{n-1} b_j \cdot y\left[t-(n-j)\cdot T\right] =$$
$$= y\left[t+n\cdot T\right];\ t\ = \{t_1, t_2, ..., t_N\} \qquad (2)$$

We use the reduced notation for (2) in the form of $Y\cdot\bar{\beta} = \overline{y_0}$. The solution of this system using the method of the least squares according to [12] represents a problem finding the best approximation of the elements—the vectors of Fourier basis $\{Y\}$, for the vector $\overline{y_0}$. However, it cannot be realized because the model uses Toeplitz matrices that are close to being singular.

In [11], the impossibility to generate reliable results is noted for solving the systems of equations with such matrices. In the conditions of weak dynamism of the signals, which is characteristic for flight information, the use of models (1) and (2) in algorithms for processing flight test information becomes impossible. Therefore, there is a problem of development of new more efficient algorithms.

They are offered to be formed using the principles of information monitoring when the algorithms access the database where the aprioristic information, gathered during the previous test flights, is stored. Using them, stages of algorithm execution we shall present as a sequence of computing operations implemented using operators of mapping of the calculation data. With the help of them, they move in the information circuit and are supplemented with the aprioristic data.

Since analog objects are considered, their characteristics are mapped into the characteristics of discrete operators $G(z,T)$ as a result of time quantization. This transformation is realized by the operator $F1(p,z,T)$:

$$\begin{pmatrix} W(p) = A(p,\bar{a})/Q(p,\bar{b}) \\ x(p);\ y(p) \end{pmatrix} \Rightarrow F1(p,z,T) \Rightarrow$$
$$\Rightarrow \begin{pmatrix} :\ G(z,T) = A(z,\bar{\alpha})/B(z,\bar{\beta}) \\ x(z);\ y(z) \end{pmatrix} \qquad (3)$$

The $F1(p,z,T)$ is a nonlinear compacting operator. It is because the infinite left complex semi-plane, in which the operators *W(p)* of stable objects are formed, is mapped into the area of the unit circle in the second space. The poles of the operator $q_i$ will be transformed according to the formula $Fz(T) * q_i \Rightarrow (b = \exp(q_i \cdot T)$ so that for the whole characteristic polynomial we have:

$$F1(p,z,t) * \{Q(p) = (p-q_1)(p-q_2)...(p-q_n)\} \Rightarrow$$
$$\Rightarrow \{B(z) = (z-\exp(q_1\cdot T))\cdot(z-\exp(q_2\cdot T))\cdots$$
$$\cdots(z-\exp(q_n\cdot T))\} \qquad (4)$$

On the basis of *G(z, T)*, the system of equations (2) is formed. This operation is realized by the operator $F2(p,z)$:

$$\begin{pmatrix} G(z,T) = C(z,\bar{\alpha})/B(z,\bar{\beta}) \\ x(z);\ y(z) \end{pmatrix} \Rightarrow F2(p,z) \Rightarrow$$
$$\Rightarrow \left(\left[X\ Y\right]\cdot\left[\bar{\alpha}\ ;\bar{\beta}\right] = \bar{y}\right) \qquad (5)$$

Because of the compacting properties of the operator $F1(p,z,T)$, substantial errors may occur. The area of the discrete poles, because of its small size, is absorbed by the area of the experimental and methodical noise. The position of poles becomes uncertain and it is impossible to restore the analog operator from them. The procedure of identification in the traditional models ends with finding the solution of the system (2):

$$\left(\left[X\ Y\right]\cdot\left[\bar{\alpha}\ ;\bar{\beta}\right]^T = \bar{y}\right) \Rightarrow F3 \Rightarrow \left(\left\|\bar{\hat{\alpha}}\ ;\bar{\hat{\beta}}\right\|\right) \qquad (6)$$

Using the method of the least squares, we get:

$$\begin{bmatrix} \bar{\alpha} \\ \bar{b} \end{bmatrix} = ([X;Y]^T \cdot [X;Y])^{-1} \cdot ([X;Y]^T y) \qquad (7)$$

However, this vector has an abstract character and has no relation to the physical nature of the object:

$$\left(\left[\bar{\hat{\alpha}}\,;\bar{\hat{\beta}}\right]\right) \Rightarrow F4 \Rightarrow$$
$$\Rightarrow \left(\hat{W}(p) = A(p,\bar{\hat{a}}) \big/ Q(p,\bar{\hat{b}})\right) \qquad (8)$$

The reliability of the results in traditional models is estimated using the value of the discrepancy of the system of difference equations:

$$\left(\left[\bar{\hat{\alpha}}\,;\bar{\hat{\beta}}\right]\right) \Rightarrow F4 \Rightarrow$$
$$\Rightarrow \left(\left\{\min[X\ Y] \cdot \left[\bar{\hat{\alpha}}\,;\bar{\hat{\beta}}\right] - \bar{y}\right\}\right) \qquad (9)$$

However, minimal discrepancy can also be achieved at the wrong results. The result $\left\lfloor \bar{\hat{\alpha}}\,;\bar{\hat{\beta}} \right\rfloor$ should be transformed into analog operator *W(p)*, and then the output signal should be calculated from it and compared with the real signal:

$$\left[\bar{\hat{\alpha}}\,;\bar{\hat{\beta}}\right] \Rightarrow F5 \Rightarrow$$
$$\Rightarrow \begin{pmatrix} \hat{W}(p) = A(p,\bar{\hat{a}}) \big/ Q(p,\bar{\hat{b}}) \\ x(p);\, y(p) \end{pmatrix} \Rightarrow$$
$$\Rightarrow F6 \Rightarrow (y(t)) \qquad (10)$$

However, in practice, it is not done. Therefore, an alternative model of identification we shall develop on the principles of information monitoring with the use of the aprioristic data. Algorithms should be formed on the basis of more advanced Fourier systems, than the systems used in the model of identification (1).

### Estimating the characteristics of usability of the method of information monitoring

The error of the method can be measured using the stationarity of changes of the vector of spectral coefficient. The nonlinear properties of operators of mapping, first of all, the operators F1, F5 (3, 10), deform the isometric properties of working spaces and are a source of methodical errors. They can be measured from the value of $\theta_i$ of the change of spectral characteristics $\mu_i(t_j);\quad t_j \in [t0 = (t_1 \cdots t_2)]$:

$$\theta_i = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left\|\bar{\mu}_i - \bar{\mu}_0\right\|}\,;\quad N = (t_2 - t_1)/T \qquad (11)$$

They are functions of time and are defined by the expression:

$$\mu_i(t) = (Y_i^T \cdot Y_i)^{-1} \cdot \left[Y_i^T \cdot \bar{y}_0(t)\right]$$
$$t0 = (t_1 \cdots t_2) \qquad (12)$$

Formally they represent a certain dynamic process generated by the operator of mapping F3 (6) on the interval t0.

The spectral characteristics determined in two different bases are not equal:

$$\mu_i(t) \neq \mu_j(t);$$
$$\mu_i(t) = (Y_i^T \cdot Y_i)^{-1} \cdot (Y_i^T \cdot \bar{y}_0);$$
$$\mu_j(t) = (Y_j^T \cdot Y_j)^{-1} \cdot (Y_j^T \cdot \bar{y}_0);$$
$$\bar{y}_0 \notin \{Y_i\} \qquad (13)$$

$$\theta_i = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left\|\bar{\mu}_i - \bar{\mu}_0\right\|}$$
$$N = (t_2 - t_1)/T \qquad (14)$$

The value of $\theta_i$ is used in the space *G(z)*:

$$\xi_i(t) = (\Psi_i^T \cdot \Psi_i)^{-1} \cdot \left[\Psi_i^T \cdot \bar{\theta}_0(t)\right]$$
$$t0 = (t_1 \cdots t_2) \qquad (15)$$

For a linear stationary object, this function should be constant. This statement follows from (2), where such vector should have a constant value. A conclusion from that follows, that for the estimation of algorithm usability, the characteristics of stationarity of Fourier systems can be used. The accuracy of algorithm can be measured on the basis of the best approximation. For this purpose, let's use a more accurate characteristic than the one used in [12]. It consists in the measurement of projections of vectors $\bar{y}_0(t)$ and $\bar{\theta}_0(t)$ on the Fourier bases. Using the matrices of projection, we get:

$$U_i(t) = Y^T{}_i \cdot \left[Y_i^T \cdot Y_i\right]^{-1} \cdot Y_i^T$$
$$S_i(t) = \Psi_i^T (\Psi_i^T \cdot \Psi_i)^{-1} \cdot \Psi_i^T \qquad (16)$$

Then the deviations of vectors from the subspaces of bases are:

$$u_i(t) = \overline{y}_0(t) - U_i \cdot \overline{y}_0(t) = (I - U_i) \cdot \overline{y}_0(t)$$
$$s_i = \overline{\theta}_0(t) - S_i \cdot \overline{\theta}_0(t) = (I - S_i) \cdot \overline{\theta}_0(t) \qquad (17)$$

From here we get the angular values of deviations:

$$\varphi_Y(t) = arctg\left( \frac{\left\| (I - U_i) \cdot \overline{y}_0(t) \right\|}{\left\| U_i \cdot \overline{y}_0(t) \right\|} \right)$$

$$\varphi_\Psi(t) = arctg\left( \frac{\left\| (I - S_i) \cdot \overline{\theta}_0(t) \right\|}{\left\| S_i \cdot \overline{\theta}_0(t) \right\|} \right) \qquad (18)$$

These phase values and their discrepancy characterize the isometric properties of the operators of mapping in the circuit of information monitoring:

$$\Delta\theta_j^{(i)} = \phi_{Yj}^{(i)} - \phi_{Wj}^{(i)}$$

$$\varepsilon\varphi_Y = \sqrt{\frac{1}{N} \sum_{i=1}^{N} \left( \varphi_Y(t_i) - m\varphi_Y \right)^2}$$

$$m\varphi_Y = \frac{1}{N} \sum_{i=1}^{N} \varphi_Y(t_i) \qquad (19)$$

$$\varepsilon\varphi_\Psi = \sqrt{\frac{1}{N} \sum_{i=1}^{N} \left( \varphi_\Psi(t_i) - m\varphi_\Psi \right)^2}$$

$$\varepsilon\varphi_\Psi = \frac{1}{N} \sum_{i=1}^{N} \varphi_\Psi(t_i) \qquad (20)$$

We shall note that the isometric properties of algorithm of information monitoring can be improved due to the introduction of additional values formed from approximating values. It allows to optimize the characteristics of the bases:

$$y_j(t) \Rightarrow Y_j(t)$$
$$Y_j(t) = \sum_{i=1}^{m} a_{ji} \cdot t^i; \quad Y_j(t) \Rightarrow a_j \qquad (21)$$

$$\overline{a}^{\,(k+1)} = (\Gamma^T \cdot \Gamma)^{-1} \cdot (\Gamma^T \cdot \overline{y(t)})$$
$$\overline{\left( \Gamma^T \right)}_j = \left[ 1, (jt)^2, (jt)^3, \cdots, (jt)^k \right] \qquad (22)$$

**Using additional working spaces in the circuit of information monitoring**

The end result is the calculation of parameter estimates of the analog operator *W(p)* and the discrete operator *G(z)*:

$$W(p) = \frac{A(p)}{B(p)} = \sum_{j=0}^{m} p^j \cdot r^j \Big/ \sum_{i=0}^{n} p^i \cdot b^i \qquad (23)$$

$$G(z) = Fz(z,T) * \left[ I(z,p) \cdot W(p) \right] =$$
$$= \frac{R(z)}{B(z)} = \sum_{j=0}^{k} r^j \cdot z^j \Big/ \sum_{i=0}^{n} z^i \cdot b^i \qquad (24)$$

As it is apparent from the series expansion of these operators, there is a nonlinear relation between them that distorts the isometric properties between the spaces of these operators:

$$W(p) \Rightarrow s_0 p^{-1} + s_1 p^{-2} + s_2 p^{-3} + \ldots$$
$$\ldots + s_k p^{-(k+1)} + \ldots \qquad (25)$$

$$G(z) \Rightarrow d_0 z + d_1 z^{-u-1} + d_2 z^{-2} + d_3 z^{-3} + \ldots$$
$$\ldots + d_k z^{-k} z^{-k} + \ldots \qquad (26)$$

Therefore, it is useful to introduce additional working spaces, consisting of weight functions of operators, between these spaces:

$$h(t) = s_0 + s_1\, t + s_2\, \frac{1}{2!} t^2 +$$
$$+ s_3\, \frac{1}{3!} t^3 + \ldots \qquad (27)$$

$$d_i = h(iT) = s_0 + s_1 iT + s_2\, \frac{(iT)^2}{2!} + \ldots$$
$$\ldots + s_k\, \frac{(iT)^k}{k!} + \ldots \qquad (28)$$

This relation can be represented in matrix form:

$$\overline{d^{(m)}} = \Gamma \cdot D_1\, D_2\, \overline{s}^{(k)}; k > n \qquad (29)$$

Here:

$$[\,\Gamma\,]_{ij} = (i-1)^{\,j-1}$$

$$[D_1]_{ij} = \begin{cases} 1/(i-1),\ if\,(i = j) \\ 0,\ if\,(i \neq j) \end{cases}$$

$$[D_2]_{ij} = \begin{cases} T^{i-1},\ if\ (i=j) \\ 0,\ if\ (i \neq j) \end{cases} \tag{30}$$

In [2], it has been proved, that:

$$[\Gamma]^{-1} = P \cdot D_1^{-1} \cdot B$$
$$[B]_{ij} = (-1)^{(i-j)} \cdot \begin{pmatrix} i-1 \\ j-1 \end{pmatrix}$$
$$P_{ij} \in Pol^{(j-1)}(x) \tag{31}$$

Here the vectors-columns of the matrices P are formed from the coefficients of polynomials:

$$Pol^{(j)}(x) = \prod_{i=0}^{j-1} (x-i)$$

Further we get:

$$\bar{s} = D_2^{-1} \cdot D_1 \cdot [\Gamma]^{-1} \cdot \bar{h} \tag{32}$$

Substituting (31), we have:

$$\bar{s} = D_2^{-1} \cdot D_1 \cdot P \cdot D_1^{-1} \cdot B \cdot \bar{d} \tag{33}$$

In [2], with the application of the method of symbolical combinatory models, the expressions for relations between the coefficients of the vector $\bar{s}$ and the coefficients of *W(p)* have been proved.

From here the conclusion follows, that for estimating the characteristics of the object, it is useful to use their weight functions. It is obvious, that in this case it is possible to provide the isometric properties of spectral vectors in the space of output signals and in the space of weight functions:

$$\mu_i(t) = (Y_i^T \cdot Y_i)^{-1} \cdot \left[ Y_i^T \cdot \bar{y}_0(t) \right]$$
$$t0 = (t_1 \cdots t_2) \tag{34}$$

$$H = \left[ (X^T \cdot X)^{-1} \right] \cdot X^T [\cdot Y] \tag{35}$$

This operator is generated on the basis of discrete analogue, which expresses the integral of convolution. We shall show, that there is an isometry between the fragments of the weight function and the output signal at the given input signal *x(t)*. The spectral vectors in their spaces have the expressions:

$$\overline{\mu_Y} = (Y^T \cdot Y)^{-1} \cdot (Y^T \cdot \bar{y}_0) \tag{36}$$

$$\overline{\mu_H} = (H^T \cdot H)^{-1} \cdot (H^T \cdot \bar{h}_0) \tag{37}$$

The vector of the weight function can be expressed as:

$$\overline{h_0} \Rightarrow H \cdot \overline{\mu_Y} = $$
$$= H \cdot (Y^T \cdot Y)^{-1} \cdot (Y^T \cdot \bar{y}_0) \tag{38}$$

Further we get:

$$Y = X \cdot H \quad (Y^T \cdot Y)^{-1} \Rightarrow$$
$$\Rightarrow \left( H^T \cdot \left( X^T \cdot X \right) \cdot H \right)^{-1} \tag{39}$$

$$Y^T \cdot \bar{y}_0 = \left( H^T \cdot X^T \right) \cdot \bar{y}_0 \tag{40}$$

By transforming the vector:

$$\overline{h_0} \Rightarrow H \cdot (Y^T \cdot Y)^{-1} \cdot (Y^T \cdot \bar{y}_0) \tag{41}$$

we turn it into:

$$\overline{h_0} \Rightarrow \left( H \cdot H^{-1} \right) \cdot \left( X^T \cdot X \right)^{-1} \cdot$$
$$\cdot \left[ \left( H^T \right)^{-1} \cdot H^T \right] \left( X^T \cdot \bar{y}_0 \right) \tag{42}$$

Taking into account that:

$$X^T \cdot \bar{y}_0 \Rightarrow \left( X^T \cdot X \right) \cdot \overline{h_0} \tag{43}$$

we get:

$$\overline{h_0} \Rightarrow H \cdot \left[ \left( H^T \cdot \left( X^T \cdot X \right) \cdot H \right)^{-1} \right] \cdot$$
$$\cdot \left( H^T \cdot X^T \right) \cdot \bar{y}_0 \tag{44}$$

After simplifications, we find that for square matrix H the following relation is true:

$$\overline{h_0} \Rightarrow \left( X^T \cdot X \right)^{-1} \cdot \left( X^T \cdot \bar{y}_0 \right) \tag{45}$$

This expression proves the existence of an isometry between Fourier systems in the spaces *{Y}* and *{H}*.

The matrix of the input signal *X* should not have a Toeplitz character. That could influence the usability of the algorithm. At the flight test stage, when the characteristics of the plane are being identified, such situation can be avoided by programming influences on the aircraft controls. We shall prove this statement.

Let's assume, that within the interval of observation the influence *x(t)* can be approximated by the function:

$$x(t)=\sum_{i=1}^{m} a_{j\,i}\cdot t^{i}; \quad x(iT)=\sum_{i=1}^{m} a_{j\,i}\cdot (iT)^{i}$$

Its vector of coefficients is found using the formula:

$$\bar{a}(T)^{\ (k+1)} = (\Gamma^{T}\cdot\Gamma)^{-1}\cdot(\Gamma^{T}\cdot\overline{x(t)})$$

$$\overline{(\Gamma^{T})}_{j} = \left[1,(jt)^{2},(jt)^{3},\cdots,(jt)^{k}\right] \qquad (46)$$

Here T is the sampling period. Having designated $\overline{q_k}^{\,T} = \left[1\; 2^{k}\; 3^{k}\; 4^{k}\cdots N^{k}\right]$ for an element $\left[X^{T}\cdot X\right]_{i,j}$ we get the following expression of matrix elements:

$$\left[X^{T}\cdot X\right]_{i,j} = (a_i\cdot a_j)\cdot s_{i\,j}\,;\; s_{i\,j} = \sum_{r=1}^{n}\bar{q}_{i+j} \qquad (47)$$

Using the operation of direct product, we get:

$$\left[X^{T}\cdot X\right] = S\otimes A; \quad A=\bar{a}(T)\cdot\bar{a}(T)^{T} \qquad (48)$$

Further we get the inverse matrix:

$$\left[X^{T}\cdot X\right]^{-1} = Dg(A)^{-1}\cdot S^{-1}\cdot Dg(A)^{-1} \qquad (49)$$

In [3, 4], it has been shown, that in such matrix, the products of the differences of poles of operator *X(p)* are used. For steady dynamic processes, they are small. Therefore, their products are close to zero and it leads to occurrence of conditions of matrix singularity. So, by programming influences, it is possible to generate the matrix *X* with the necessary configuration.

## Experimental confirmation of usability of method of information monitoring for processing dynamic information

Let's consider the possibility to use the algorithm for identification of parameters of aircraft equipment during the flight test stage. The most crucial flight mode that involves the greatest risks is the mode of automatic landing using the signals of the instrument landing system's antenna arrays. The control system for this mode includes the block for filtering the noise, the level of which is different for each airport. The channel of the filter is described by a third order differential equation. It can be presented in the operator form:

$$W(p) := \frac{(\tau_1)^2\cdot p^2 + 2\cdot\tau_1\cdot\zeta_1\cdot p + 1}{\left[(\tau_2)^2\cdot p^2 + 2\cdot\tau_2\cdot\zeta_2\cdot p + 1\right]\cdot(\tau_3\cdot p + 1)}\cdot K1 \qquad (50)$$

For the formation of the model of identification it is more convenient to use the form:

$$W(p) := K\cdot\frac{p^2 + \left(\frac{2\cdot\zeta_1}{\tau_1}\right)\cdot p + \frac{1}{(\tau_1)^2}}{\left[p^2 + \frac{(2\cdot\zeta_2)}{\tau_2}\cdot p + \frac{1}{(\tau_2)^2}\right]\cdot\left(p + \frac{1}{\tau_3}\right)} \qquad (51)$$

The signal at the output of the filter is defined by the form of the input signal coming from the antenna array. We shall use a difficult form:

$$X(p) := \frac{rx_0 + rx_1\cdot p}{p^2 + qx_1\cdot p + qx_0}$$

$$X(p) := \frac{3 + p}{6.41 + 0.8\cdot p + p^2} \qquad (52)$$

It will allow to test the method for a higher order differential:

$$Y(p) := \frac{40 + 20\cdot p + 11.6p^2 + p^3}{256.4 + 160.2p + 130.356p^2 + 35.69p^3 + 12.4p^4 + p^5} \qquad (53)$$

In the technical documentation the values of nominal parameters of the filter for which it can be used are given:

$$\tau 0 = \begin{bmatrix}0.3\\0.5\\0.1\end{bmatrix} \quad \varepsilon\tau = \begin{bmatrix}0.1\\-0.12\\0.15\end{bmatrix}$$

$$\varsigma 0 = \begin{bmatrix}0.8\\0.4\end{bmatrix} \quad \varepsilon\varsigma = \begin{bmatrix}0.15\\-0.12\end{bmatrix} \qquad (54)$$

Let's create a working calculation space from such parameters, assigning them values at which it is considered, that the filter is in failure condition:

$$\tau = \tau 0\cdot(1 + i\cdot\varepsilon\tau)\,; \quad \xi = \varsigma 0\cdot(1 + i\cdot\varepsilon\varsigma) \qquad (55)$$

Let's make six variants of parameters variation:

$$\tau := \begin{pmatrix} 0.3 & 0.33 & 0.36 & 0.39 & 0.42 & 0.45 \\ 0.5 & 0.44 & 0.38 & 0.32 & 0.26 & 0.2 \\ 0.1 & 0.115 & 0.13 & 0.145 & 0.16 & 0.175 \end{pmatrix}$$

$$\zeta := \begin{pmatrix} 0.8 & 0.92 & 1.04 & 1.16 & 1.28 & 1.4 \\ 0.4 & 0.352 & 0.304 & 0.256 & 0.208 & 0.16 \end{pmatrix} \quad (56)$$

It is obvious, that with the variations of parameters there will be corresponding variations of the output signals $(\Delta\tau; \quad \Delta\varsigma) \Rightarrow \Delta y(t)$. For the sampling period T=0.02s, the matrix of signals is calculated as:

$$Y = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0.0192 & 0.0195 & 0.0197 & 0.0199 & 0.0201 & 0.0202 \\ 0.0371 & 0.0382 & 0.039 & 0.0396 & 0.0402 & 0.0405 \\ 0.054 & 0.0561 & 0.0578 & 0.0591 & 0.0602 & 0.0609 \\ 0.0699 & 0.0733 & 0.0761 & 0.0783 & 0.0799 & 0.0809 \\ 0.085 & 0.0899 & 0.0939 & 0.097 & 0.0993 & 0.1003 \\ 0.0995 & 0.106 & 0.1112 & 0.1154 & 0.1182 & 0.119 \\ 0.1135 & 0.1215 & 0.1281 & 0.1331 & 0.1364 & 0.1368 \end{pmatrix} \quad (57)$$

The errors of mapping were calculated using the formulas specified in the program module. For the interval of observation with 30 values of the output signal and the sampling period T = 0.05s, the errors in recovering the vectors $\bar{\tau}_i$ ; $\bar{\varsigma}$, averaged over all 6 variants, were less than 2% ($\delta\tau$ = 1.183%; $\delta\varsigma$ = 1.395%).

It indicates that between the information spaces with the use of mapping of Fourier systems, there is an algebraic isomorphism and an isometry, on the basis of which, models of identification that do not use numerically unstable Toeplitz matrices can be formed.

Let's show, that the existence of these properties is possible if there are deterministic relations between the parameters of mathematical objects. On the basis of this condition, the method of information monitoring for optimization of the characteristics of identification models can be used for processing of the flight information.

## Conclusions

The specific properties of application of identification models of characteristics of aircraft and their equipment are related to the bad observability of the dynamic properties of objects. They are characteristic for all aerospace objects. In many respects, they are a result of flight restrictions, which should be carried out, proceeding from the flight safety requirements. Therefore, the characteristics of usability can change in an unpredictable way and lead to meaningless results. The classical methods of regularization cannot improve the situation. However, a practical need for identification algorithms is great. At the aircraft flight test stage, they can help to gather additional amount of valuable information.

For the improvement of the properties of algorithms, essentially new information technologies, which are taking into account the deterministic relations between various dynamic parameters, can be used. It allows to completely change the structure of algorithms and to improve their numerical stability. The algorithms are constructed on the principles of mapping the dynamic characteristics into a circuit of working information spaces. In the area of maximum allowed deviations of object parameters, the properties of algebraic isomorphism and the isometry of mapping operators are preserved. It allows to use the aprioristic information, which has been gathered during the design stage and during the previous test flights, in a mathematical way. Such approach allows to extensively manipulate the characteristics of numerical stability of algorithms and to optimize them.

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**G.Burovs. Informācijas tehnoloģijas lidmašīnu testa lidojumiem paredzēto algoritmu veiktspējas uzlabošanai**

Rakstā apskatīta efektīvu algoritmu radīšana lidmašīnas un tās aprīkojuma raksturojumu novērtēšanai izmēģinājumu lidojumu laikā. Uzdevums tiek risināts izmantojot identifikācijas modeļus, kas ir piemēroti ar lidmašīnas sensoru izmērīto dinamisko procesu apstrādei. Ir izdarīts secinājums par tradicionālo modeļu, kas balstās uz statistiskiem principiem ar regresijas analīzes metodes izmantošanu, nepilnībām. Lidojumu drošības prasības neļauj radīt tādus lidojuma režīmus, kuros varētu iegūt pilnu informāciju par objekta dinamiskajiem raksturojumiem. Tādēļ vienādojumu sistēmas, kas ir veidotas no signālu mērījumu rezultātiem, ir vāji nosacītas un kļūdas to risinājumos ir jutīgas pret trokšņu iedarbību. Šādi algoritmi dod kļūdainus rezultātus un nevar tikt izmantoti. Bez tam, algoritma efektivitāte ir atkarīga no to struktūras. Teplica (Toeplitz) tipa mērījumu rezultātu matricu izmantošana identifikācijas modeļos nav pieļaujama, jo tā tiek iegūti kļūdaini rezultāti. Piedāvātie algoritmi balstās uz apriorās informācijas par objektu izmantošanu. Informācijas tehnoloģijas to radīšanai tiek apskatītas pamatojoties uz dinamiskās informācijas attēlošanu aprēķinu telpu ķēdē. Ir pierādīts, ka darba stāvokļu apgabalā objekts var tikt identificēts ar praktiskai lietošanai piemērotu precizitāti. Šī pieeja ļauj optimizēt algoritmu efektivitātes raksturojumus. Izmantojot tos, ir iespējams iegūt ievērojami vairāk informācijas par lidmašīnas un tās aprīkojuma raksturojumiem nekā līdz šim. Tas ļauj samazināt izmēģinājumu cikla ilgumu un izdevumus.

**Г. Буров. Информационные технологии повышения работоспособности алгоритмов, используемых на этапе летных испытаний самолетов**

Рассматривается проблема создания работоспособных алгоритмов оценивания характеристик самолета и его оборудования на этапе летных испытаний. Задача решается с применением моделей идентификации, пригодных для обработки динамических процессов, измеряемых датчиками сигналов самолета. Делается вывод о несовершенстве традиционных моделей, основанных на статистических принципах с применением методов регрессионного анализа. Требования обеспечения безопасности полета не позволяют создавать режимы полета, в которых можно было бы получать полностью наблюдаемую информацию о динамических параметрах объекта. По этой причине системы уравнений, формируемые по результатам измерений сигналов, плохо обусловлены и погрешности их решений чувствительны к воздействию помех. Такие алгоритмы дают ошибочные результаты и неработоспособны. Кроме того работоспособность алгоритмов зависит от их структуры. Использование в моделях идентификации матриц результатов измерений типа теплицевых недопустимо, поскольку результаты получаются ошибочными. Предложенные алгоритмы основаны на использовании априорной информации об объектах. Информационные технологии их создания рассматриваются с позиций отображения динамической информации в цепи расчетных пространств. Доказывается, что в области рабочих состояний объект может быть идентифицирован с удовлетворительной для практики точностью. Указанный подход позволяет оптимизировать характеристики работоспособности алгоритмов. На их основе может быть получено значительно больше информации о характеристиках самолета и его оборудования, чем обычно. Это позволяет сократить продолжительность цикла летных испытаний и снизить материальные затраты.