# IDENTIFICATION OF CHARACTERISTICS OF AEROSPACE OBJECTS AND THEIR EQUIPMENT AT FLIGHT TEST STAGES

# AEROKOSMISKO OBJEKTU UN TO APRĪKOJUMA RAKSTUROJUMU IDENTIFIKĀCIJA IZMĒĢINĀJUMA LIDOJUMU LAIKĀ

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***The problem of application of special flight modes of aerospace objects is examined with the purpose of reliable identification of their characteristics. The work is motivated by the necessity of obtaining additional amounts of information at the flight test stages and processing this information using the latest developments in information technologies. The starting point for solving this problem is coordination of the parameters of test flight modes with the mathematical structure of identification models. Such opportunities exist at the flight test stages, but they are inadmissible at the stages of everyday operation for reasons of flight safety. Such approach allows to improve the reliability of identification of aerodynamic characteristics of aircraft and their onboard equipment. Gathering additional information during the test flights allows to reduce the duration of flight test cycle and to considerably reduce expenses required to design new objects of aerospace systems.***

## Introduction

Creation of mathematical models that accompany the flight test cycle of objects of aerospace systems allows to reduce its duration and to lower the expenses. They allow to detect various phenomena and shortcomings that were not predicted beforehand and to find the most effective ways for their elimination, which reduces the number of required test flights. The active use of accompanying modelling can lead to the reduction of number of flight test by up to 30%. The importance of its application increases with the increase of the number of necessary flight tests, as they increase the cost of projects [17, 19].

The role of models is especially important in the identification of aerodynamic characteristics of aerospace objects. The greatest amount of work is made during the tests of models in wind tunnels. However, they do not allow to completely investigate the influence of aerodynamic characteristics on the flight stability and controllability of objects. Such information could be obtained during the real flight at the flight test stage, but it is hindered by the small degree of observability of the flight information because of the flight restrictions that are necessary for the conditions of flight safety. They do not allow to make the flight maneuvers at which the aerodynamic characteristics would be shown to the full extent and the information necessary for mathematical models of identification would be obtained. Another obstacle is the onboard control systems that dampen the short-term oscillations of aircraft, from which it would be possible to determine its aerodynamic properties. Gathering of the necessary information is blocked also by the systems of stabilization of flight trajectory.

However, at the flight test stage, unlike the modes of everyday operation, special flight modes are realized for gathering the necessary information, but it is connected to additional risks and an additional psychological pressure on the operator. Therefore, to reduce those, the intensity and character of strictly dosed test influences on the aircraft controls is specified in the test flight plan that ensure that the flight mode will be within the limits of flight restrictions.

## Statement of the problem

Because of the abovementioned properties of flight modes, it would be expedient to automate a part of the operations for the research of aerodynamic characteristics of aerospace objects and their equipment. It could be realized in onboard computers possessing the properties of supercomputers. Using modern information technologies, it is possible to realize efficient models for identification of characteristics of aerospace objects. However, the problem of gathering the flight information with the necessary degree of dynamism still remains. Models of identification are connected to solving mathematically incorrect problems of inverse type. It means that all algorithms of identification have a common property – a high sensitivity to noise and methodical errors in the determination of model structure. The less is the dynamism of analyzed processes, the less is their usability and the reliability of obtained results. Thus, two problems that at first sight are separate: the problem of maintaining the necessary mathematical properties of identification models and the problem of choosing the characteristics of flight modes appear to be closely related. Therefore, both of them should be solved in coordination, and their realization is possible only with the use of new information technologies.

An obstacle for identification of characteristics of aerospace objects is the small degree of observability of the information gathered by the sensors. The full range of the stabilizer deviation angle of a modern maneuverable airplane is approximately 40-45 degrees. But, during flight, the maximal deviations of the stabilizer are extremely rare and stabilizer settings with the deviation angles rarely exceeding 3-5 degrees are used for the determination of the characteristics of stability and controllability of the airplane.

The standard technique for determining the characteristics of airplane stability is using sharp, nearly instant alterations of controls; therefore, there is a rapid change of the airplane angle of attack or angle of sideslip. But, since the influence of the angle of attack and the angle of sideslip on the uniformity of the pressure of air flow at the input of aircraft engines and, therefore, on the characteristics of the engine operation, is not determined yet, such sequence of actions is dangerous. Sharp maneuvers of the airplane that are possible in such situation, the characteristics of stability of which are not yet investigated, cannot be considered safe enough. Therefore, when first entering the investigated mode of flight, estimation of airplane behaviour (using small, smooth alterations of controls) and operation of engine (using smooth alterations of engine controls) should be done at the beginning, and then, at the absence of abnormalities, the characteristics are determined according to the requirements of techniques [17].

The procedure of application of test influences can be improved if it is realized proceeding from the requirements of maintaining the functionality of the models of identification of aircraft and its engine's aerodynamic characteristics. In this case, it is possible to use such modes of flight that will not lead to flight parameters leaving the limits of flight restrictions and to occurrence of dangerous situations. Using more efficient models of identification, more smooth and safe control alteration can be used.

Therefore, this paper investigates the possibility of formation of efficient models of identification due to the use of the special flight modes that provide the observability of information about the characteristics of aerospace objects. The problem is examined in relation to airplane tests, as in these tests there are more ample opportunities for variation of characteristics of flight modes. However, the obtained results can also be used at the flight test stage of carrier rockets.

## Models of identification of airplane aerodynamic characteristics using the aprioristic information

Gathering the information about the aerodynamic characteristics of an airplane has important practical value. At present the information mostly comes from the ground-based tests of their models in wind tunnels. However, these tests have long duration and are expensive. For example, the number of wind tunnel tests during testing of the F-16 aircraft was about 300 [17]. But, it is impossible to guarantee beforehand the full coincidence of the aircraft characteristics calculated on the basis of wind tunnel tests with the real characteristics. Therefore, gathering information about the aerodynamic characteristics during real flight can reduce the number of wind tunnel tests leading to reduced duration of the test cycle and lower expenses.

The coordination of models of identification of aerodynamic characteristics with the parameters of the flight mode is necessary because these characteristics can change over a wide range with the change of the airplane configuration: extending and retracting flaps and undercarriage, changing the angles of control surfaces and so on. Especially strongly they can change during flight in a turbulent atmosphere. Therefore, mathematical models of identification of aerodynamic characteristics are necessary to adapt to a concrete flight mode.

During formation of reasonable models of identification, it is expedient to use the aprioristic information, obtained at the design stage and during the wind tunnel tests. This information is frequently present in a generalized form of transfer functions, which are the most useful for formation of mathematical models of identification [16].

We shall consider this problem on the example of the operator describing the angular movements of the airplane in the longitudinal plane [16, 18]:

$$W_{\omega Z,\delta B}(p) = \frac{p\vartheta(p)}{\delta(p)} \quad (1)$$

$$W_{\omega Z,\delta B}(p) = \frac{Kc_{\vartheta,\delta B}\cdot(T_\theta p + 1)}{T^2 p^2 + 2\xi \cdot Tp + 1}\cdot \cdot\frac{K_\delta}{T_\delta p + 1} \quad (2)$$

This operator relates the input signal going from the onboard computer to the flight control system and the output signal coming from the pitch angular velocity sensor. Here the transfer operator of the flight control system, which takes into account its inertial properties, is included that allows to improve the accuracy of the identification model.

The advantage of using such operator is that its parameters are related by mathematical relations to the parameters of the airplane and its aerodynamic characteristics [16, 18, 19]. A significant number of parameters are known (the characteristics of wings, the weight of the airplane, etc.) and their values can be substituted in these relations. It considerably facilitates their further decoding and allows to obtain estimations of aerodynamic characteristics that are impossible to measure in a direct way. Transfer operators in the yaw and roll channels will have a similar structure; they differ only by the rules of control.

The development of identification models we shall make on the basis of the method of information monitoring described in [3, 5, 6, 8, 14]. For estimating the accuracy of the algorithm of identification we shall set the following values of parameters for carrying out the mathematical modeling: $T_\theta$ = 2; $T_\vartheta$ = 1; $\xi_\vartheta$ = 0.8; $T_\delta$ = 0.25.

Because the coefficient of amplification can be determined in static mode, the parameters of a transformed operator are identified:

$$W_0(p) = W\ (p) \cdot K$$

$$W\ (p) = \frac{p+d}{p^3 + q_2 p^2 + q_1 p + q_0}$$

$$K = \frac{T_\theta}{T_\vartheta{}^2 \cdot T_\delta} \cdot K_u \tag{3}$$

Here:

$$\bar{q}^{\,T} = [4\ 7.4\ \ 5.6\ 1];\ d = 0.5 \tag{4}$$

As the input influence, a decaying sine wave signal is used, the image of which is:

$$X(p) = \frac{p+h}{(p-c)^2 + \omega^2}$$
$$h = 0.8;\quad c = -0.6 \tag{5}$$

$$x(t) = \exp(c \cdot t) \cdot \left[ \left( \frac{h+c}{\omega} \right) \cdot \sin(\omega \cdot t) + \cos(\omega \cdot t) \right] \tag{6}$$

Operator (3) contains complex conjugate poles. The operator of the output signal *Y(p)* is:

$$Y(p) = W(p) \cdot X(p) = wY(p) + xY(p) \tag{7}$$

$$wY(p) = \sum_{i=1}^{n} \left( \frac{wRzl_i}{p - wKor_i} + \frac{wRzl^*{}_i}{p - wKor^*{}_i} \right) \tag{8}$$

$$xY(p) = \sum_{i=1}^{m} \left( \frac{xRzl_i}{p - xKor_i} + \frac{xRzl^*{}_i}{p - xKor^*{}_i} \right) \tag{9}$$

Here, the coefficients of decomposition and poles have the following values:

$$rzlY = \begin{bmatrix} 0.0813 & -0.0423 & 0.001642 \\ 0 & 0.0794 & -0.1478 \end{bmatrix}$$

$$korY = \begin{bmatrix} -4 & -8 & -0.6 \\ 0 & 0.6 & 1.2 \end{bmatrix} \tag{10}$$

The values of the signal and its derivatives, calculated with the step $T$ = 0.1 sec on the time interval from 0 to 1 sec are shown in Table 1, while the Fig. 1 shows the graph of the output signal *y0(t)* and its first derivative on the time interval from 0 to 2 sec.

Table 1

Output signal and its derivatives

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| y0(iT) | 0.0042 | 0.0139 | 0.0262 | 0.039 | 0.051 | 0.0615 | 0.0699 | 0.0761 | 0.08 | 0.0817 |
| y1(iT) | 0.0758 | 0.1143 | 0.1281 | 0.1258 | 0.1134 | 0.0949 | 0.0732 | 0.0504 | 0.0278 | $6.3169 \times 10^{-3}$ |
| y2(iT) | 0.5467 | 0.2444 | 0.0456 | –0.082 | –0.1604 | –0.2046 | –0.2251 | –0.2291 | –0.2217 | –0.2065 |
| y3(iT) | –3.6827 | –2.4408 | –1.5882 | –1 | –0.5925 | –0.3093 | –0.1122 | 0.0244 | 0.118 | 0.1806 |

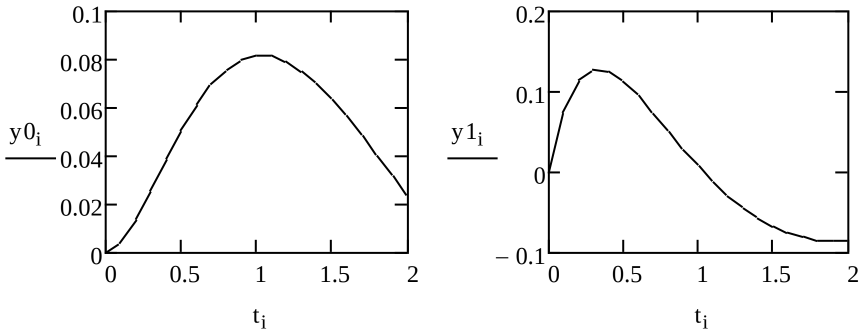


Fig. 1. Output signal and its first derivative

For the formation of identification model on the principles of information monitoring, we use the results described in [3, 5, 6, 14]. The experimental information is displayed into the calculation space using the generating operators investigated in [10]. Correctness of the choice of the structure of identification model of [1] can be checked using the balance function [1], the image of which is formed on the basis of operators (3), (5) and (7):

$$D(p) = \frac{p^2 + \alpha_1 p + \alpha_0}{p^5 + \beta_4 \cdot p^4 + \beta_3 \cdot p^3 + \beta_2 \cdot p^2 + \beta_1 \cdot p + \beta_0} \qquad (11)$$

The image of the making operators is found according to the method stated in [8]. The values of the coefficient vectors of 5th order operators are given in Table 2. They have been calculated at the basic time points specified in the first row.

On the basis of these coefficients, the system of identification equations for determining the parameters of the operator (3) was formed. They were compared to the values of parameters (4) and the percentage errors of deviations were calculated (see Table 3). The first column of the table shows the orders of the used generating operators. From the data in table follows that there is an optimal information space of 5th order operators in which the most accurate results of identification have been obtained.

The usability of the identification models was estimated from the characteristics of the conditionality of the solved equation systems that are shown in Table 4. As such, the values of determinants and the condition numbers of matrices of the solved equation systems have been used.

Table 2

Coefficient vectors of the 5th order display operator for the algorithm of information monitoring

| t(sec) | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 |
|---|---|---|---|---|---|---|---|---|
| $Kf_0$ | 0.039 | 0.051 | 0.061 | 0.07 | 0.076 | 0.08 | 0.082 | 0.081 |
| $Kf_1$ | 0.126 | 0.113 | 0.095 | 0.073 | 0.05 | 0.028 | $6.317 \times 10^{-3}$ | –0.013 |
| $Kf_2$ | –0.041 | –0.08 | –0.102 | –0.113 | –0.115 | –0.111 | –0.103 | –0.093 |
| $Kf_3$ | –0.166 | –0.098 | –0.051 | –0.018 | $4.244 \times 10^{-3}$ | 0.02 | 0.03 | 0.037 |
| $Kf_4$ | 0.194 | 0.135 | 0.094 | 0.065 | 0.045 | 0.031 | 0.02 | 0.012 |
| $Kf_5$ | –0.106 | –0.074 | –0.052 | –0.037 | –0.026 | –0.019 | –0.014 | –0.011 |

Table 3

Percentage errors of identification of parameters of the operator (3)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| n | 0.1s | 0.1s | 0.2s | 0.3s | 0.4s | 0.5s | 0.6s | 0.7s |
| 4 | 1.05 | 1.04 | 1.08 | 1.15 | 1.25 | 1.37 | 1.5 | 1.62 |
| 5 | 0.16 | 0.16 | 0.17 | 0.19 | 0.2 | 0.17 | 0.27 | 0.26 |
| 6 | 1.26 | 0.85 | 1.26 | 1.29 | 2.95 | 2.2 | 4.11 | 1.66 |
| 7 | 14.13 | 100.13 | 471.3 | 529.96 | $1.3\times10^{4}$ | 814.23 | $3.13\times10^{3}$ | 594.38 |

Table 4

Parameters of numerical stability for the models of identification of parameters of the operator (3)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| t(sec) | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 |
| $det_t$ | $1.94\times10^{-7}$ | $1.07\times10^{-7}$ | $5.86\times10^{-8}$ | $3.22\times10^{-8}$ | $1.77\times10^{-8}$ | $9.77\times10^{-9}$ | $5.41\times10^{-9}$ | $3.01\times10^{-9}$ |
| $Cond_t$ | $4.22\times10^{4}$ | $4.07\times10^{4}$ | $3.92\times10^{4}$ | $3.74\times10^{4}$ | $3.48\times10^{4}$ | $3.16\times10^{4}$ | $2.78\times10^{4}$ | $2.33\times10^{4}$ |

## Choice of parameters of test flight mode from the condition of maintaining the functionality of identification models

From the data in Table 4 follows that in the process of transient decay, the functionality of the identification model is reduced. It confirms the conclusions described above that it is expedient to coordinate the parameters of the flight mode with the characteristics of functionality of identification model. It is possible to confirm this conclusion using the example of a special flight mode when an impulse type influence is applied to the channel of airplane control in the longitudinal plane. The expediency of using such flight modes has been proved mathematically on the basis of the theorem of decomposition of identification model.

For calculating the output signal, the expression of the reaction to a step function was used:

$$Y(p) = W(p)\cdot X(p) = \\ = wY(p) + xY(p) + \frac{c}{p} \qquad (12)$$

Here the components *wY(p)*, *xY(p)* are defined by the expressions (8) and (9). For a rectangular impulse, the difference of reactions to a step function, shifted in time by *T0* is taken (see Fig. 2). The decomposition coefficients and poles of the operator are:

$$Rzl2 := \begin{pmatrix} -1.037735849056603\times10^{-1} & 8.25471698113207\times10^{-2} \\ -1.367924528301886\times10^{-1} & 0 \end{pmatrix}$$

$$Kor2 := \begin{pmatrix} -8\times10^{-1} & -4\times10^{0} \\ 6\times10^{-1} & 0 \end{pmatrix}$$

Table 5 shows the values of parameters of the transfer function (3) and Table 6 shows the errors of their identification.

From the Table 6, it is visible that in the flight mode with the application of impulse test influences, the accuracy of identification has increased in comparison with the case of application of a decaying sine wave signal. The change of the coefficients of the generating operators depending on time is shown in Table 7. There is a significant correlation between these coefficients (see Table 8). In the Table 9, the characteristics of conditionality of the system of identification equations are given.

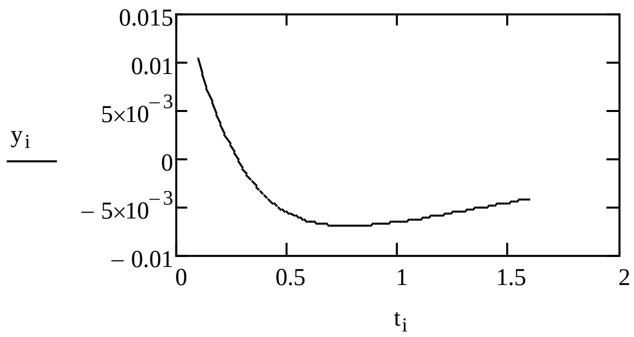


Fig. 2. Reaction to the influence in the form of a step function

Table 5

Results of identification of parameters of the operator (3)

| $t_i$(sec) | 0.0 | 0.06 | 0.12 | 0.18 | 0.24 | 0.3 | 0.36 | 0.42 |
|---|---|---|---|---|---|---|---|---|
| n5 | 3.995 | 3.995 | 3.996 | 3.998 | 3.996 | 3.993 | 3.997 | 3.995 |
| n6 | 7.393 | 7.392 | 7.394 | 7.397 | 7.394 | 7.389 | 7.395 | 7.392 |
| n7 | 5.596 | 5.596 | 5.596 | 5.597 | 5.596 | 5.595 | 5.596 | 5.596 |

| $t_i$ | 0 | 0.06 | 0.12 | 0.18 | 0.24 | 0.3 | 0.36 | 0.42 |
|---|---|---|---|---|---|---|---|---|
| n5 | 0.7366 | 0.737 | 0.7372 | 0.7358 | 0.7357 | 0.7373 | 0.737 | 0.7345 |
| n6 | 0.0959 | 0.1051 | 0.0857 | 0.0447 | 0.0869 | 0.1407 | 0.0705 | 0.1046 |
| n7 | 1.432 | 0.4184 | 1.1393 | 1.7852 | 3.8886 | 3.7684 | 3.2974 | 10.123 |

Table 6

Percentage errors of identification of the operator (3)

Table 7

Change of coefficient vectors of the 6th order generating operator

| 0sec | 0.06sec | 0.12sec | 0.18sec | 0.24sec | 0.3sec | 0.36sec | 0.42sec |
|---|---|---|---|---|---|---|---|
| 0.024 | 0.016 | 0.01 | $5.912\times 10^{-3}$ | $2.402\times 10^{-3}$ | $-2.777\times 10^{-4}$ | $-2.304\times 10^{-3}$ | $-3.816\times 10^{-3}$ |
| –0.143 | –0.112 | –0.086 | –0.067 | –0.051 | –0.039 | –0.029 | –0.022 |
| 0.299 | 0.236 | 0.185 | 0.146 | 0.115 | 0.09 | 0.071 | 0.056 |
| –0.397 | –0.313 | –0.246 | –0.194 | –0.153 | –0.12 | –0.095 | –0.075 |
| 0.392 | 0.308 | 0.243 | 0.191 | 0.15 | 0.118 | 0.093 | 0.073 |
| –0.292 | –0.229 | –0.18 | –0.142 | –0.112 | –0.088 | –0.069 | –0.054 |
| 0.131 | 0.103 | 0.081 | 0.064 | 0.05 | 0.04 | 0.031 | 0.024 |

Table 8

Correlation coefficients and phase characteristics

| t(sec) | 0 | 0.06 | 0.12 | 0.18 | 0.24 | 0.3 | 0.36 |
|---|---|---|---|---|---|---|---|
| $\rho(t_i)$ | 1 | 0.9999 | 0.9998 | 0.9996 | 0.9992 | 0.9985 | 0.9974 |
| $\phi$(rad) | $4.899\times 10^{-3}$ | 0.0112 | 0.0189 | 0.0284 | 0.0402 | 0.0548 | 0.0728 |
| $\phi$(grad) | 0.2807 | 0.6431 | 1.0841 | 1.6287 | 2.3034 | 3.1386 | 4.169 |

Table 9

Characteristics of conditionality of the 6th order operator

| t(sec) | 0 | 0.06 | 0.12 | 0.18 | 0.24 | 0.3 | 0.36 |
|---|---|---|---|---|---|---|---|
| $\det(t_i)$ | $-6.54\times 10^{-8}$ | $-4.67\times 10^{-8}$ | $-3.34\times 10^{-8}$ | $-2.39\times 10^{-8}$ | $-1.71\times 10^{-8}$ | $-1.22\times 10^{-8}$ | $-8.71\times 10^{-9}$ |
| $\mathrm{Cond}(t_i)$ | $2.13\times 10^{4}$ | $1.79\times 10^{4}$ | $1.5\times 10^{4}$ | $1.25\times 10^{4}$ | $1.05\times 10^{4}$ | $8.71\times 10^{3}$ | $7.25\times 10^{3}$ |

Comparing the data in Tables 4 and 9, we see that in the flight mode with application of impulse test signal, the functionality of the identification model has increased. It confirms the conclusion about expediency of coordination of the parameters of the flight mode with the characteristics of the identification model.

## Identification of characteristics of aerospace objects at the presence of systematic errors

At the flight test stage, very important is studying the reasons of occurrence of vibrations and oscillations of the vehicle's body. In multistage carrier rockets, a particular danger is posed by elastic oscillations of the rocket's body and oscillations of the liquid matter in the fuel tank. Modes of elastic oscillation $u_i(t)$ can occur, the frequencies of which partially coincide with the working frequency range. The elastic deformation of the rocket leads to a situation where the angular sensor placed on the gyroscopically stabilized platform measures the angle $\vartheta = \vartheta_0 + \sum_{i=1}^{m} \varphi_i \cdot u_i(t)$ that differs from the actual angle by the value caused by bending of the rocket's body. The control system perceives this as a true signal and starts to amplify the oscillations of the rocket.

Vibration can result in accumulation of metal fatigue stresses and defects in riveted construction parts. The resulting stresses in the structure cannot be detected by the flight acceleration sensors [17]. The probability of these phenomena is especially high during flights in turbulent atmospheric zones where flutter modes can occur. In such situation aerodynamic characteristics of the lifting surfaces can considerably change. It happens because of the change of local angles of attack of lifting surface fragments and it is the reason of the occurrence of flutter. Identification of characteristics of flutter modes at the flight test stage represents a special interest as it allows to determine the area of flight restrictions [17] which will provide flight safety at everyday operation of aerospace objects. Research of the reasons of occurrence of vibrations and flutter phenomena is so important that special angular velocity sensors for their identification are placed in different control points on airplane wings. To increase their sensitivity to vibrations and to realize their identification, the range of frequency characteristics is deliberately shifted in such sensors.

Thus, the identification of characteristics of noise and disturbances has an important practical value. These questions are solved by applying various mathematical models. The basic model is the one considered in [15]. In this model, the operator of the identified object $G(q,\theta)$ is related to the operator of noise $H(q,\theta)$ by the relation:

$$y(t) = G(q,\theta)u(t) + H(q,\theta)e(t) \quad (13)$$

Here $e(t)$ is a sequence of mutually independent random variables with zero mean and dispersion $\lambda$. The Gaussian character of $e(t)$ is assumed.

Therefore, there is an interest for application of model (13) for identification of vibrations and elastic oscillations arising in an aerospace object and its equipment. However, because of the features of flight modes, the precondition about Gaussian character of disturbances will probably not always hold to the full degree. It is obvious that, because of the rapidity of the change of flight parameters, the method of "coefficient freezing" can only be applied on very short time intervals. Therefore, there can be difficulties with gathering of "representative statistics" about disturbances. Introduction of the operator $H(q,\theta)$ leads to an expansion of model's dimensions. In conditions of small signal dynamism that were mentioned above, it can create additional difficulties in maintaining the necessary numerical stability of algorithms for solving the systems of difference equations. They are formed on the basis of the operator of Z-transform $\varphi\, Z(T)$ which is used to transform the analog operator of the differential equation:

$$W(p) = \frac{R(p)}{Q(p)} = \frac{p^n + q_{n-1}p^{n-1} + \ldots + q_1 p + q_0}{b_m p^m + b_{m-1}p^{m-1} + \ldots + b_1 p + b_0} \quad (14)$$

into the discrete form [4, 14]:

$$D(z) = \varphi\, Z(T) * W(p) \Rightarrow \frac{A(z)}{B(z)} = \frac{\alpha_m z^m + \alpha_{m-1} z^{m-1} + \ldots + \alpha_1 z + \alpha_0}{z^n + \beta_{n-1} z^{n-1} + \ldots + \beta_1 z + \beta_0} \quad (15)$$

Irrespective of the form of the operator $\varphi\, Z(T)$, the following nonlinear relation always exists between analog and discrete poles:

$$\{\xi_i = \exp(-a_i T)\} \Leftrightarrow \left\{ a_i = -\frac{Ln(\xi_i)}{T} \right\} \quad (16)$$

Operator (15) is the generating operator for formation of the system of difference equations. Therefore, the following rule is always observed: the distance between adjacent column vectors in the matrix is determined by the discrete step *T*, a parameter of the operator $\varphi\, Z(T)$. The desire to improve the accuracy of approximation in (15) by reducing *T* inevitably leads to increased linear dependence of column vectors and, as a result, to occurrence of singularity. Because of this, in [14] and other similar works, an approach based on introduction of an operator of interpolating filter in $\varphi\, Z(T)$ was developed, allowing wider changes of *T*.

However, it did not solve the problem of numerical stability of algorithms. Generally, the matrix of the system has Toeplitz character, which by definition is numerically unstable. The reasons for occurrence of singularity and difficulties in overcoming it are examined in [20, 21]. Unfortunately, the phenomenon of singularity is a typical situation for all models of identification without exception. The situation is complicated by drawbacks of computing algorithms based on the method of elimination.

This has served as a stimulus for development of new mathematical method based on methods of computing symbolical combinatory models. Their application has allowed to obtain a number of important theoretical results [9, 10, 11, 12, 13], in particular, to derive in a general analytical form the expression for the inverse matrix of the system of identification equations and its solution. From these results follows that the parameters of the introduced operator of noise $H(q,\theta)$ will be incorporated in all elements of the inverse matrix in the form of multiplier fragments. Therefore, additional identification with the purpose of isolating the parameters of the operator $G(q,\theta)$ from the total solution is required. Generally, such problem seems to be intractable.

The efficiency of application of symbolical combinatory models for solving identification problems has been proved in work [13] in which inverse 20th order Hilbert matrix has been calculated with 100% accuracy. This matrix is considered the standard of singularity and it is believed that determining it for orders larger than 10th is impossible even with the help of modern supercomputers. This new mathematical method allows to solve other important practical problem – the problem of creating parallel computing algorithms which allow to considerable reduce the time necessary to solve identification problems. It is important for speeding up the processing of flight information in the onboard computers of aerospace objects in real-time during test flight.

From expressions (14), (15), and (16) follows that the results of solving the systems of difference equations are abstract numbers and their additional identification is required. Identification should be adapted to the needs of the practical user and he/she should receive results that would reflect the physical nature of the object. These questions never are mentioned in known publications, possible because there are insurmountable mathematical difficulties related to the properties of the operations of direct and inverse Z-transform. They are visible from the relation (16).

At the direct transform, there occurs information compression: the analog poles located in the left infinite half-plane (steady objects are considered) are displayed into a narrow area of the right unit half-circle. With the reduction of *T*, needed to increase the accuracy of approximation, the distances between them decrease. In the presence of noise, which includes the round-off errors, these distances are overwhelmed by noise. As a result, the whole set of discrete poles is perceived as one multiple pole. The algorithm of the inverse Z-transform thus cardinally changes its structure. The problem of decoding the primary results of identification becomes intractable.

Because of this, in [3, 5, 6, 14] alternative methods of decoding, based on the principles of information monitoring, have been developed. Efficiency of their application has been proved in the previous section. Measurements of correlation characteristics of the vectors of generating operators given in Tables 7 and 8, indirectly confirm the properties of structural filtration of the method of information monitoring and the possibility of its application for identification of characteristics of vibrations and elastic oscillations of aerospace object bodies.

We shall consider this problem using the example from the previous sections. With this purpose, we shall add a disturbance to the working signal used for flight control, as it is shown in Fig. 3. The noise/signal ratio, calculated on the time interval 0-2 sec, was 1.28. Applying the method of identification described in previous sections, we get the results of identification of the operator (3). A high accuracy of identification was observed; its errors are displayed in Table 10. This allowed to isolate the disturbance and its root mean square was equal to its original value.

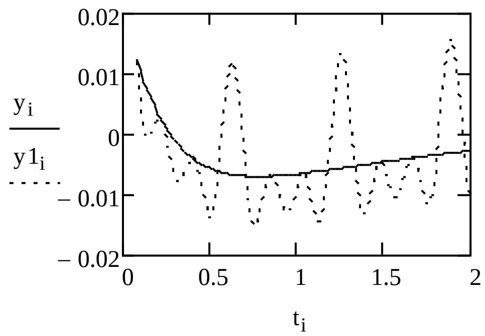


Fig. 3. The working signal and the added disturbance

Table 10

Percentage errors of identification in conditions of additive systematic disturbance

| $t_i$(sec) | 0.02 | 0.04 | 0.06 | 0.08 | 0.1 | 0.12 | 0.14 |
|---|---|---|---|---|---|---|---|
| n4 | 3.3008 | 3.3011 | 3.3011 | 3.301 | 3.301 | 3.3009 | 3.3009 |
| n5 | 0.7486 | 0.7398 | 0.7363 | 0.75 | 0.7296 | 0.7248 | 0.7067 |
| n6 | 0.2181 | 0.1473 | 0.1214 | 0.061 | 0.275 | 0.1939 | 0.9925 |
| n7 | 14.4268 | 1.5213 | 6.4244 | 25.3966 | 30.2083 | 32.4075 | 97.5297 |

From the obtained results follows that the initial disturbance has a systematic character and, consequently, assumptions about its random character and Gaussian distribution are not required, as it is the case in the model (13). It considerably expands the possibilities of practical application of this method.

## Conclusions

For the formation of models of identification of aerodynamic characteristics of aerospace objects it is expedient to use the aprioristic information gathered at the design stage and during previous test flights. Algorithms of identification are expedient to realize in onboard computers and use them in the modes of real test flights. It allows to supplement the information gathered during ground tests in wind tunnels with the information gathered during flight that takes into account all factors of the real air conditions. Is such case the duration of the flight test cycle and the material expenses can be reduced.

Parameters of a concrete flight mode are expedient to coordinate with the mathematical characteristics of the model of identification, which allows to use numerically stable algorithms for processing of the flight information. Application of the method of information monitoring allows to carry out identification in the transformed calculation space of generating operator characteristics with the accuracy that allows its practical use. Results of mathematical modelling have shown that the developed algorithm allows to filter not only normally distributed noise, but also systematic disturbances.

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**J.Grundspeņķis, G.Burovs. Aerokosmisko objektu un to aprīkojuma raksturojumu identifikācija izmēģinājuma lidojumu laikā**
Rakstā apskatīta aerokosmisko objektu īpašu lidojuma režīmu izmantošana to raksturojumu ticamai noteikšanai. Šī problēma ir svarīga papildus informācijas iegūšanai izmēģinājuma lidojumu laikā un šīs informācijas apstrādei izmantojot jaunākās informācijas tehnoloģijas. Problēmas risinājuma izejas punkts ir izmēģinājuma lidojumu režīmu parametru saskaņošana ar identifikācijas modeļu matemātisko struktūru. Izmēģinājumu lidojumu laikā tas ir iespējams, bet sērijveida ekspluatācijas laikā lidojuma drošības apsvērumu dēļ tas nav pieļaujams. Šāda pieeja ļauj paaugstināt lidaparātu un to aprīkojuma identifikācijas ticamību. Iegūtā papildus informācija ļauj samazināt izmēģinājuma lidojumu skaitu un samazināt ar tiem saistītos izdevumus izstrādājot jaunus aerokosmisko sistēmu objektu modeļus.

**Я. Грундспенкис, Г. Буров. Идентификация характеристик аэрокосмических объектов и их оборудования на этапах летных испытаний**
Рассматривается проблема применения особых режимов полета аэрокосмических объектов с целью достоверной идентификации их характеристик. Она рассматривается с позиций получения дополнительных объемов информации на этапе летных испытаний и ее обработки с применением новейших информационных технологий. Отправной точкой решения этой проблемы является согласование параметров испытательных полетных режимов с математической структурой моделей идентификации. Такие возможности существуют на этапах летных испытаний и недопустимы на этапах серийной эксплуатации из соображений безопасности полетов. Такой подход позволяет улучшить достоверность идентификации аэродинамических характеристик летательных аппаратов и их бортового оборудования. Получение дополнительной информации в процессе испытательных полетов позволяет сократить цикл летных испытаний и значительно снизить материальные затраты при разработке новых образцов объектов аэрокосмических систем.