Information Technologies for Creating Algorithms and Software for Flight Tests of Aircraft Pre-Production Designs

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***Abstract* - The possibility of using new information technologies for signal processing at the aircraft flight test stage is investigated. Since there are restrictions imposed on flight modes, the identification of parameters of aircraft its equipment is carried out in the conditions of bad observability of the dynamic characteristics. It complicates the problem of ensuring the usability of computing algorithms for solving the systems of equations formed from the results of measurements of the flight parameters. The traditional algorithms are based on the principle of consecutive execution of computing operations. Therefore, the possibility of application of new information technologies for the creation of algorithms with parallel structure is investigated. It will allow to apply parallel computers and to increase speed of information processing. In this case, there is an opportunity to apply more advanced algorithms for the control of dangerous modes of flight. Such problem is solved for the aircraft takeoff run mode. The new information technologies are offered to be realized on the basis of symbolical combinatory computing models.**

***Keywords:* aircraft takeoff run, algorithm usability, flight mode, identification, parallel algorithms, symbolical combinatory computing models**

I. Introduction

Aircraft flight tests are high-risk tasks, therefore, special attention is given to safety measures at all stages of preparation for carrying out these tests. The necessity of processing huge amounts of information over short time intervals during test flights demands using high-performance onboard computers and more advanced programs and algorithms.

For example, the number of parameters that describe the test flight and the behavior of the aircraft, the work of the glider and the onboard systems subject to measurement, measured during the flight tests of the American aircraft B-1 exceeded 3000 [15]. It demands wider application of mathematical modeling to accompany the flight tests. According to experts, the use of such modeling allows to reduce the duration of the test phase by 30% and to reduce the test-related expenses. Wider introduction of mathematical modeling at the flight test phase will also allow to increase the flight safety and to receive much more information about the characteristics of stability and controllability of the aircraft and also about the quality of functioning of the new onboard equipment in real modes of flight.

Special attention is given to the most dangerous modes of flight, first of all, to the takeoff and landing modes. The analysis of functions that are carried out by the control system at the takeoff mode shows that it is necessary to use new higher performance onboard computers and more advanced control algorithms. Such problems can be solved by introducing information technologies constructed on novel principles.

It is necessary to take into account that the signals taken from the measuring sensors have smooth-changing character and such signals are difficult to process using traditional computing algorithms. It is a general feature of all objects in aerospace systems and it is dictated by the restrictions on flight modes, which are introduced to ensure the flight safety.

Therefore, the traditional algorithms related to the central problem of information processing: solving the systems of equations, generated on such low-dynamic signals, turn out to be inapplicable as they cannot preserve the needed accuracy in conditions when the matrix of the system is close to being singular. Such algorithms return false results that can lead to making wrong decisions during the flight and during the inter-flight analysis. For this reason, the theoretical models of identification suggested in numerous publications could not be used in practical applications.

The structure of these algorithms is based on the principles of consecutive execution of computing operations. Therefore, they are not well suited for their realization in high-performance parallel computer. From here follows that for creation of more advanced systems of onboard measurements used in test flights, it is necessary to introduce the new technologies, allowing to realize parallel principles of information processing. On the basis of such technologies, essentially new computing methods can be created that would allow to preserve the high accuracy in conditions of ill-conditionality of matrices of equation systems. In this case, the development of adaptive computing models with adjustable structure, which can be realized by software methods, is possible.

Symbolical combinatory (SC) models were constructed not on the basis of known classical methods of enumerative combinatorics, but on the basis of giving the computing algorithms the new properties possessed by determined combinatory operators. The validity of using such approach has been confirmed by solving the problem of finding the inverses of almost singular 20^{th} order Hilbert matrices with the 100% accuracy. Earlier it was believed that solving such problem is impossible for matrices the order of which exceeds 10.

II. Using Graph Structures for Designing Algorithms and Software for Parallel Computers

Processing large amounts of information during the test flight demands the application of high-performance computers. However, their capacities cannot be fully utilized by traditional computing algorithms, which are based on the principle of consecutive execution of computing operations. Therefore, it is necessary to solve these problems using a more integrated approach. High performance can be achieved by using computers working on parallel principles, but then also the computing algorithms must be parallelized. Solving this problem was considered in the works of G. Burov, and the solution was found in the development of new information technologies that use symbolical combinatory models of the execution of computing operations.

As the basic tool for enabling the parallel operation in both computers and algorithms, the graph structures were used that allowed to solve ill-conditioned equation systems. Graph structures possess the property of fragmentation and consequently they can be used for parallelization of computing algorithms, which can then be used to improve the performance of aircraft onboard computers using software methods. Performance in this case can vary over a wide range and it is determined by the number of used processors. For their switching and work synchronization the same switching addressing schemes that are used in graphs can be used.

For the central problem of algorithms – solving ill-conditioned systems of equations formed from the results of measurements of flight processes, a graph structure, which is created on the basis of symbolical combinatory models, is used.

The advantage of the new information technologies based on graph structures is that many different approaches can be used for optimization of computing operations. They are chosen depending on the character of the problem being solved. The main principles of such optimization, however, can be specified. They are reduced to the application of methods of specification of multisets located in the graph sections that allow to allocate their carriers using the SC operators [10], [12] – [14]. Their use is facilitated by the fact that the problem is solved in the symbolical space of integers. It allows to realize the specification using the SC operators of address switching [4], [9], [11], [12]. The system of switching is formed in a separate working information space and it works in a mode of monitoring with the information space of the objects processed in arithmetic registers. Operations of switching are realized on the basis of the ordered index sequences. It allows to avoid the use of enumeration operations, which are usually used in combinatorial algorithms, and to use determined and minimized algorithms.

In the paper [1], [2], the methods for formation of such operators have been developed. Their properties are suitable for carrying out the operations of optimization of computing algorithms. It was found that operations on ordered numerical sequences, which are generated by these operators, can be replaced with operations on the arguments of these SC operators [4], [10], [12].

From here follows, that the initial software should be created in the field of the arguments of such operators. And then, using only formal mathematical methods, hierarchical principles of formation of symbolical combinatory models must be applied to obtain the software in a completed form.

The possibility of using graph structures for realization of parallel calculations follows from their properties of regularity, recursivity, decomposition, and hierarchy. It allows to apply new information technologies to design universal algorithms for processing of flight information in both the systems of onboard measurements and the ground control systems used in different stages of flight tests.

Let's present the symbolical combinatory model in the form of address lexicographic combinatorial configurations. In this model, we use the combinatorial operators developed in papers [5-11].

The graph structures used in symbolical combinatory models possess the properties of regularity, recursivity, decomposition, and hierarchy. These properties allow to apply the new information technologies for the formation of universal algorithms for processing the flight information both in systems of onboard measurements and in the ground control and measurement systems used at the flight test stages.

The symbolical combinatory computing model we shall present in the form of address lexicographic combinatorial configurations with the help of operator φDpv acting on the submatrix $H(\bar{r},\bar{L})$. Here r and $\bar{L}$ are the coordinates of the allocated submatrix:

$$V(\bar{r},\bar{L}) \Rightarrow \varphi Dpv(\bar{r},\bar{L}) * \bar{q}^{(n)}$$
$$\bar{q}^{(n)\,T} = (q_1, q_2, \cdots, q_n) \tag{1}$$

The operator $\varphi Dpv(\bar{r},\bar{L}) * \bar{q}^{(n)}$ allows to determine the structure of the graph model and it can be described analytically:

$$\begin{gathered}\varphi Gr(\bar{r},\bar{L}) : \tilde{q}_1^{(n)} \Rightarrow \varphi Dpv * [\varphi Kc(m_1) * \tilde{q}_1] \times \\ \times \varphi Dpv * [\varphi Kc(m_2) * \tilde{q}_2] \times \ldots \\ \ldots \times \varphi Dpv * [\varphi Kc(m_k) * \tilde{q}_k] \\ \sum_{\mathrm{i}=1}^{\mathrm{k}} m_i = n \end{gathered} \tag{2}$$

The sets in its sections are formed in view of the sets in the previous sections using the residual principle and described by the symbolical formula:

$$\begin{gathered}\bigcup_{i=1}^{k} \bar{q}_i^{(n_i)} \Rightarrow \bigcup_{i=1}^{k} i \circ \{\varphi Kc(v\ ) : [(i+1),(i+2),\ldots,n)]\} \\ k = n-(v-1)\end{gathered} \tag{3}$$

The expression (2) describes the graph in the form of a branching tree. Therefore the SC model of the algorithm for determining the elements of the inverse has a form of a decomposition of independent fragments as graph branches.

It proves that the graph has a parallel architecture, which can be used for representation of the algorithm for solving equation systems in a parallel form.

The properties of the operator φDpv have been investigated and the proof is found, that it possesses the filtering properties in relation to the multiset, allocating the carrier. This property can be used for the optimization of calculation process with simultaneous increase in its accuracy. Components of *Ims* containing the coordinates of the elements of the allocated submatrix are used as arguments of the operator φDpv. Therefore, all operations connected to the inversion of the matrix *Y*, first of all, of re-addressing operation, can be executed in index symbolical space:

$$\varphi Dvp(\mathrm{Im}\, s) * \tilde{q}^{(n)} \Rightarrow \Rightarrow \tilde{q}^{(n)} * Arang\left[\varphi Dvp(\bar{r}^{(n)} \times \bar{L}^{(n)})\right] \tag{4}$$

Then we shall have:

$$\varphi Dvp\left\{(\varphi Perm * \bar{r}^{(n)}) \times \bar{L}^{(n)}\right\} * \tilde{q}^{(n)} \Rightarrow \Rightarrow \tilde{q}^{(n)} * Arang\left[\left(\varphi Dvp * \bar{r}^{(n)}\right) \oplus \bar{L}^{(n)}\right] \tag{5}$$

On the basis of $\mathrm{Im}\, s = \left[\left(\overline{0.n-1}\right) \times \circ \left(\overline{0.n-1}\right)\right]$ in the SC model, the difference operators φFg [1], [4] can be introduced:

$$\varphi Fg * \tilde{q}^{(n)} \Rightarrow \coprod_{i,j(i \neq j)} q_i - q_j \tag{6}$$

$$\varphi Dvp\left\{(\varphi Perm * \bar{r}^{(n)}) \times \bar{L}^{(n)}\right\} * \tilde{q}^{(n)} \Rightarrow \Rightarrow \left[\varphi Fg(\bar{r}^{(n)}) * \tilde{q}^{(n)}\right] \cdot \left[\tilde{q}^{(n)} * Arang\left(\left(\overline{L^{(n)}}\right)\right)\right] \tag{7}$$

$$\varphi Dvp\left\{\bar{r}^{(n)} \times (\varphi Perm * \bar{L}^{(n)})\right\} * \tilde{q}^{(n)} \Rightarrow \Rightarrow \left[\varphi Fg(\bar{L}^{(n)}) * \tilde{q}^{(n)}\right] \cdot \left[\tilde{q}^{(n)} * Arang\left(r^{(n)}\right)\right] \tag{8}$$

$$\varphi Dvp\left\{(\varphi Perm * \bar{r}^{(n)}) \times \overline{(\varphi Perm * \bar{L}^{(n)})}\right\} * \tilde{q}^{(n)} \Rightarrow \Rightarrow \left[\varphi Fg(\bar{r}^{(n)}) * \tilde{q}^{(n)}\right] \times \left[\varphi Fg(\bar{L}^{(n)}) * \tilde{q}^{(n)}\right] \tag{9}$$

If $\bar{r}^{(n)} = \overline{m.\, m + (n-1)}$ then the common multiplier is allocated:

$$\varphi Dvp\left\{\varphi Perm * \left[\left(\overline{0.n-1}\right) \oplus m^{[n]}\right]\right\} * \tilde{q}^{(n)} \Rightarrow \Rightarrow \left[\tilde{q}^{(n)} * Arang(m^{[n]})\right] \cdot \left[\varphi Fg * \tilde{q}^{(n)}\right] \tag{10}$$

The conjugate property of decomposition is observed:

$$\varphi Dvp(\varphi Perm * \bar{r}^{(n)}) * \left[\tilde{q}^{(n)} * Arang(\bar{r}^{(n)} \oplus \bar{L}^{(n)})\right] \Rightarrow \Rightarrow \left[\tilde{q}^{(n)} * Arang\left(\varphi Dvp * \bar{r}^{(n)}\right)\right] \cdot \left[\tilde{q}^{(n)} * Arang\left(\bar{L}^{(n)}\right)\right] \tag{11}$$

$$\varphi Dvp(\varphi Perm * \bar{L}^{(n)}) * \left[\tilde{q}^{(n)} * Arang(\bar{r}^{(n)} \oplus \bar{L}^{(n)})\right] \Rightarrow \Rightarrow \left[\tilde{q}^{(n)} * Arang\left(\varphi Dvp * \bar{L}^{(n)}\right)\right] \cdot \left[\tilde{q}^{(n)} * Arang\left(\bar{r}^{(n)}\right)\right] \tag{12}$$

The SC model possesses recursive properties that allow to apply the methods of reduction of algorithm complexity. For this purpose, we shall represent the product in graph branches in the form of ordered numerical sequence *R(m, n)* [6]:

$$R(m,n) \Rightarrow \sum_{\nu=1}^{m} \varphi Perm * \left\{\left[\varphi KC(\nu) * \overline{1.n}\right] * \varphi Arng(Z_\nu)\right\} \qquad Z_\nu \Rightarrow \varphi Perm * \left[\varphi Part(\nu) * m\right] \tag{13}$$

It has the following property:

$$G(m,n) \Rightarrow (\overline{0.m-1}) \oplus R(m,n) \tag{14}$$

On their basis, lexicographic forms for Kronecker products of vectors can be generated:

$$\varphi \Pi r(m) * \left(\overline{1.n}\right) \Rightarrow R(m,n) \qquad \varphi \Pi r(m) * \left(\overline{1.n}\right) \Rightarrow \varphi KC(m) * \left[\left(\overline{1.n}\right) - (\overline{0.m-1})\right] \tag{15}$$

Using the above described properties, we have:

$$\varphi Dvp(\varphi Perm * \bar{r}^{(n)}) * G(m,n) \Rightarrow \Rightarrow \varphi Dpv(\varphi Perm * \bar{r}^{(n)}) * \left[\varphi KC(m) * \left(\overline{1.n}\right)\right] \tag{16}$$

$$\varphi Dvp\left\{(\varphi Perm * \bar{r}^{(n)}) \times \bar{L}^{(n)}\right\} * G(m,n) \Rightarrow \Rightarrow \tilde{q}^{(n)} * Arang\left\{\begin{matrix}\varphi Dpv(\varphi Perm * \bar{r}^{(n)}) \\ * \left[\varphi KC(m) * \left(\overline{1.n}\right)\right]\end{matrix}\right\} \tag{17}$$

Using the property of decomposition of the operator φDpv, we shall find:

$$\varphi Dvp * \left[Q^{(n \times m)} \cdot P^{(m \times n)}\right] \Rightarrow \bar{u}^{T} \cdot \bar{h} \tag{18}$$

$$\left[\overline{u}\right]_i \Rightarrow \varphi Dvp * Q_i^{(n\times n)}$$
$$\left[\overline{h}\right]_i \Rightarrow \varphi Dvp * P_i^{(n\times n)} \quad (19)$$

The coordinates of submatrices are used as arguments of the operator φDpv.

As them, we use the vectors made from the components of ordered numerical sequences [6]:

$$\overline{G(n,m)} = (\overline{0.n}) \oplus \overline{R(n,m)}:$$
$$\left[\overline{u}\right]_i \Rightarrow \varphi Dvp\left[\left(\overline{1.n} \times \circ G(n,m)_i\right)\right] * Q;\ \left[\overline{h}\right]_i \Rightarrow$$
$$\Rightarrow \varphi Dvp\left(G(n,m)_i \times \overline{1.n}\right) * P \quad (20)$$

Then the expression (1) can be written down in the following form:

$$\varphi Dvp * \left[Q^{(n\times m)} \cdot P^{(m\times n)}\right] \Rightarrow$$
$$\Rightarrow \varphi Sum * \left\{\left[\varphi Dvp(\overline{\arg}_1) * Q\right] \otimes\right.$$
$$\left.\otimes \left[\varphi Dvp(\overline{\arg}_2) * P\right]\right\} \quad (21)$$

$$\overline{\arg}_1 \Rightarrow \left[\overline{1.n}\right] \times \circ \overline{G(n,m)}^T$$
$$\overline{\arg}_2 \Rightarrow \overline{G(n,m)} \times \circ \left[\overline{1.n}\right] \quad (22)$$

Let's find the argument set for φDpv, acting on the product $\left[\underline{Q^{(n\times m)} \cdot M^{(m\times m)} \cdot W^{(m\times n)}}\right]$. With the help of the vector $\underline{ims}_i \Rightarrow G(n,m)_i \times \circ G(n,m)$, we shall allocate a submatrix $S^{(n\times m)}_i \in M^{(m\times m)}$. Using (4), we find:

$$\overline{\arg}\left[\varphi Dpv * \left(S_i \cdot W\right)\right] \Rightarrow \left[\overline{G(n,m)}_i \times \circ \overline{G(n,m)}^T\right]_M \otimes$$
$$\otimes \circ \left[\overline{G(n,m)} \times \circ \left(\overline{1.n}\right)\right]_W \quad (23)$$

$$Arg\left(\varphi Dpv * M^{(m\times m)}\right) \Rightarrow \quad (24)$$

The result of the influence of the operator φDpv we shall write down as:

$$\varphi Dpv * \left[Q^{(n\times m)} \cdot M^{(m\times m)} \cdot W^{(m\times n)}\right] \Rightarrow \overline{d}^T \cdot Z \cdot \overline{w}$$
$$\Rightarrow \left\{\overline{G(n,m)} \times \circ \overline{G(n,m)}^T\right\}_M \quad (25)$$

$$\overline{d}^T \Rightarrow \varphi Dpv\left\{\left(\overline{1.n}\right) \times \circ \overline{G(n,m)}\right\} * Q$$
$$\overline{w} \Rightarrow \varphi Dpv\left\{\left(\overline{1.n}\right) \times \circ \overline{G(n,m)}\right\} * W$$
$$\left[Z\right]_{ij} \Rightarrow \varphi Dpv\left\{\overline{G(n,m)}_i \times \circ \overline{G(n,m)}^T_j\right\} * M^{(m\times m)} \quad (26)$$

Using the result (28) and the expression (18) [1], we find the SC model for the inverse matrix of the dynamic process:

$$Y^{-1} \Rightarrow \varphi Dpv\left\{\left(\overline{G(n,m)} \times \circ \overline{G(n,m)}\right)\right\} * Y \Rightarrow$$
$$\Rightarrow \left[\varphi Dpv * W(\overline{G(n,m)})\right] \cdot$$
$$\cdot \left[\varphi Dpv\left\{\left(\overline{G(n,m)} \times \circ \overline{G(n,m)}\right)\right\} * M^{(k\times k)}\right] \cdot$$
$$\cdot \left[\varphi Dpv * W(\overline{G(n,m)})\right] \quad (27)$$

From the derived expressions follows that the systems of equations can be solved in parallel modes without the use of the critical operations of division.

From the expressions (16, 17) follows that they can be expressed as a decomposition, the fragments of which can be processed independently. Thus, the SC model of the computing algorithm has a parallel architecture. Its structure can be changed flexibly by changing the parameters of operators of the combinatory operators that are included in the SC model. It allows to coordinate the architecture of the algorithm with the parallel architecture of the computer using software methods.

The model allows to obtain the solution in a scaled space using numerically stable mathematical operations. The solution can be expressed in the form of direct product of two matrices of the output results from the solution of the mathematical model. And all further operations can be carried out with the scaled data

The optimization of algorithms can be carried out on the basis of methods of filtration in the information space of address structures. This method is described for realization of operations connected with the operations such as Cartesian products. The used method of filtration allows to obtain the results in the form of canonical combinatory configurations [11, 10, 12, 14]. Solving practical problems of information processing with the use of method of filtration automatically results in minimized structures in which the carrier structure is extracted. The redundancy of the initial structure is minimized due to the calculation of numerical specifiers, and they are found in a determined way, instead of using the methods of combinatorial search.

III. Development of Algorithm for Control of Aircraft Takeoff Run in the Takeoff Mode of Flight Test

This mode is the most dangerous at the stage of flight tests of the pre-production designs of the aircraft. In this situation, the properties of the aircraft are unknown and mistakes in decision-making about the termination of the takeoff in case of emergency are possible. The performance of the onboard computers is not sufficient for realization of more advanced and reliable algorithms for the control of the takeoff mode. The task of the algorithm is to determine whether the aircraft can, in case of emergency, use the braking to finish the takeoff run within the limits of the remaining reserve of runway length. Finding the solution is carried out in two stages. First, it is necessary to calculate beforehand the change of the parameters describing the course of the process of takeoff run under the actual conditions of the takeoff. Second, it is necessary to compare the actual current values of the parameters with the calculated ones during the takeoff run, and, if they diverge in an adverse direction, to give the signal for the termination of the takeoff.

From that follows that there is a problem of creating a mathematical model that simulates the process of takeoff run of the aircraft with the calculation of the distance traveled on the runway and values of its first and second derivatives. If one of engines fails and the length of a runway is not sufficient to carry out braking, the aircraft should continue the takeoff.

During the takeoff run, it is necessary to compare the real course of process with the calculated one. The calculated values of speed can be either calculated directly during the run or be calculated preliminary and stored in the memory of onboard computer. The first variant of construction of the control system is the most preferable, but it demands application of rather high-performance onboard computer, capable to solve in real time the differential equation with rather complex structure of the right-side part. This is a standard equation that was used in the development of numerous modification of takeoff indicators. It is solved using numerical methods and the dependence of speed from the distance traveled is calculated for the braking and run modes.

The longitudinal movement of the aircraft during the takeoff run is divided into two stages. At the first stage, the takeoff run is carried out on three wheels. At the second stage of takeoff, the aircraft continues the takeoff run on the main wheels, while the forward wheel does not touch the surface of the runway.

According to this, it is necessary to consider two base systems of differential equations [16].

At the first stage, the pitch angle practically does not vary. In view of this, the equation of balance is represented in the following form:

$$\frac{G}{m}\cdot\frac{d^2x}{dt^2} = P - qS(C_{X0} + C_{Y0}\cdot\theta) - F - N\cdot\theta \qquad (28)$$

$$N = G - P(\theta+\varphi) - qS(C_{Y0} - C_{X0}\cdot\theta)$$
$$V = \frac{dx}{dt} - W_X \qquad (29)$$

where

φ – the angle of engine installation;

θ – the longitudinal slope of the runway surface;

N – the force of reaction of wheels on the surface of the runway;

$F = Nf$ – the force of rolling resistance of wheels;

$f = f\left(\frac{dx}{dt}\right)$ – the factor of rolling resistance dependent on the speed and the condition of the surface of the runway.

On the second stage of takeoff run, in the equation (28) only the factors of the elevating force C_Y and the frontal resistance C_X will increase as the pitch angle increases. It is necessary to add the equation of balance of the moments relative to the transverse OZ axis to the equation (28):

$$I_Z\cdot\frac{d^2v}{dt^2} = $$
$$= qSb_a\cdot\left(m_{Z0} + m_Z{}^{\alpha}\cdot\Delta\alpha - m_Z{}^{\omega_Z}\cdot\frac{dv}{dt} - m_Z{}^{\delta}\cdot\delta\right) +$$
$$+M_P - N\cdot l_1 \qquad (30)$$

The moment of ending the takeoff run (the moment of lifting the aircraft from the surface of the runway) is determined by the equality $N = 0$ (the force of reaction of wheels on the surface of runway disappears). Until this moment, the vertical movement of the center of mass of the aircraft is insignificant and one can assume that:

$$\Delta\alpha = \Delta v - \Delta\theta \qquad (31)$$

The system of equations (28), (29), (30), (31) under the condition of $N \geq 0$ completely characterizes the longitudinal movement of the aircraft during the takeoff run.

From the equations (28) and (29), it follows that the parameters of takeoff run depend on the weight of the aircraft and the wind speed, and the force of rolling resistance of wheels, which depends on the speed and the condition of the surface of the runway. Other parameters are related to the aerodynamic characteristics of the aircraft and the force of engine thrust. From these equations, the dependences of speed $x(t)^{(1)}$ and acceleration $x(t)^{(2)}$ on the distance traveled $x(t)$ should be calculated.

The course of the process of takeoff run is determined by the solution of the equation (1). As a result, the dependences $x(t)\,;\,x^{(1)}(t)\,;\,x^{(2)}(t)$ are determined.

The parameters which are included in the differential equations (28), (29), (30), (31) are calculated by the computer of the ground computer center and the parameters of the calculated course $X(t)\,;\,X^{(1)}(t)\,;\,X^{(2)}(t)$ of the takeoff process are found by solving the equation (1). They are transferred to the onboard computer of the aircraft before the takeoff and then, in case of emergency, they are used by the algorithm for making decision about braking the aircraft or continuing the takeoff. In this algorithm, the real values of parameters $x(t)\,;\,x^{(1)}(t)\,;\,x^{(2)}(t)$, which are compared to the calculated values, are entered. The additional information about the calculated values $X^{(1)}(X)\,;\,X^{(2)}(X)\,;\,X^{(2)}(X^{(1)})$ can be entered into algorithm. These values are calculated from the dependences $X(t)\,;\,X^{(1)}(t)\,;\,X^{(2)}(t)$ by excluding the parameter of time.

The numerous indicators of takeoff patented in various countries use different combinations of controllable parameters. The choice of them is determined mainly by the simplicity and convenience of measurement. More often these parameters are time, speed, and acceleration.

Other drawback is that the acceleration $x^{(2)}(t)$ is not used as a controllable parameter in the algorithm. For control over acceleration, the condition of a satisfactory course of the takeoff is $x^{(2)}(t) \geq X^{(2)}{}_{rasc}(t)$ at any moment of time. But, as it apparent from the equation (28), the acceleration can instantly and rather strongly change, for example, because of wind gusts W_X. Yet the gust of wind can have a short duration and it would cause a very small change of speed. Therefore, the alarm signal about the termination of takeoff will be false. So, there are two controllable values: $x(t)$ and $x^{(1)}(t)$, and the actual dependence of speed on the distance traveled $x^{(1)}(x)$ needs to be compared with the calculated one. If at any value of the distance traveled the condition $x^{(1)}(t) \geq X^{(1)}{}_{rasc}(t)$ holds, the takeoff can be continued. If this condition is violated, it is necessary to stop the takeoff.

The parameters specified in the equation (28) are entered in the onboard computer. Most of them are entered from the ground control measuring systems. But the value of the distance traveled on the runway, the speed of takeoff run and the acceleration more often are determined by the onboard computer of the aircraft. For measurement of the distance traveled and traveling speed, the aircraft is equipped with various sensors. For the measurement of the distance traveled, the ground systems are used as well, measuring the distance from the aircraft to the transmitter located on the continuation of the axis of the runway. However, in this case, big expenses for aircraft equipment are required. Therefore, more often, independent ways of measurement are applied.

The mentioned drawbacks of the traditional control algorithms of takeoff mode in many respects are determined by the fact that they do not use full information about the takeoff characteristics of the aircraft. In particular, the information about the value of the second derivative is not used. Therefore, in algorithm, because of the effect of noise in the form of short-term wind gusts, an important logical condition on the satisfactory course of the takeoff process $x(t)^{(2)} \geq x(t)_0{}^{(2)}$ is not used. Instead, a more simple condition $x(t)^{(1)} \geq x(t)_0{}^{(1)}$ is used.

The analytical expressions for definition of parameters $x(t)$; $x^{(1)}(t)$; $x^{(2)}(t)$, and also higher order derivatives for the modified algorithms, we shall find proceeding from the condition of filtration of noise, among which short-term gusts of wind prevail.

From the analysis of the condition $x(t)^{(1)} \geq x(t)_0{}^{(1)}$ used in traditional algorithms, it is clear that it possesses little noise tolerance. The additive noise in the sensors can lead to significant errors. In addition, such algorithm does not possess the necessary predicting properties that would allow taking into account all tendencies in the development of the takeoff run process. For example, at this stage it would be desirable to find out all the tendencies of changes in the work of the aircraft engine. Especially dangerous are the modes when there are emergencies related to the irregularities in the work of engine. They arise when engines are hit by external objects, for example, birds. In this case, the character of engine thrust varies and the most sensitive parameter in this situation would be the acceleration of the takeoff run. To find more reliable attributes for identification of such situation, it would be necessary to supplement the acceleration signals with the higher order derivatives. However, they are impossible to measure using the onboard sensors. Taking into account, that wind perturbations can add to the engine thrust variations, the measurement of the second and higher-order derivatives becomes impossible. However, the information about them is present in the signals in a latent form.

We shall consider the possibility to measure them using software of the onboard computer without the use of additional hardware, by applying new information technologies. Solving the equations (1-4) together with the gathered empirical data allows to create a provisional dependence of the change of aircraft speed at the takeoff run for the given type of aircraft. It can be expressed, for example, as a dependence of the following type:

$$x(a,\omega,t)^{\langle 1\rangle} := K \cdot \exp(a \cdot t) \cdot (\sin(\omega \cdot t) + \\ + \cos(\omega \cdot t)) \quad (32)$$

The coefficient K is determined by the efficiency of the aircraft engine. The dependence (32) in this case is not an object of research. It is used only as an auxiliary tool for carrying out the mathematical modelling. It serves only as means of the proof of advantages and opportunities of more advanced algorithms. They can be realized on the basis of predicting functions which allow to the calculate values of higher-order derivatives. For this purpose the functions of the following kind are used:

$$\varphi(t) = a_0 + a_1 t + a_2 t^2 + \cdots + a_m t^m \quad (33)$$

If it is possible to determine the coefficients (33) from the experimental measurements of the speed of the takeoff run of the aircraft then the values of derivatives of *k*-th order can be easily derived in an analytical form:

$$\varphi(t)^{(k)} = a_k \cdot b_{0,k} + a_{k+1} \cdot b_{1,k} \cdot t + a_{k+2} \cdot b_{2,k} \cdot t^2 + \ldots + \\ + a_m \cdot b_{m-k,k} \cdot t^{m-k} \quad (34)$$

Here the adjusting coefficients turn out as product of integers of a factorial kind.

The operations with such functions were examined in [7]. Their basic property has been revealed: they are not numerically stable. This property is marked in the majority of publications. In particular, it is marked in [22, 23]. Therefore, in practice, orthogonal functions and Chebyshev polynomials, based on trigonometric functions, more often are used. However, from the analysis of dependences (32) follows, that they do not contain components of a trigonometric kind and it can lead to significant errors. Therefore, there is only one solution – to expand the opportunities of application of functions of a kind (34).

The nature of computing instability is connected to the limited possibilities to invert Hilbert matrices, which arise in such problems. It is considered, that it is impossible to invert Hilbert matrices with order higher than 10th. However, the application of the new information technologies based on symbolical combinatory computing models, described by graph structures that are described in the Section II, allows to substantially lower these restrictions. Their efficiency has been proved in the paper [21] in which an inverse Hilbert matrix of the 20th order has been calculated with the 100% accuracy.

It allows to speak about an opportunity of use the functions (34) for improving the algorithms for control of the aircraft in the takeoff modes. According to [21], their coefficients should be found from the condition of the filtration of additive noise in the signals measuring the speed of the aircraft takeoff run that should be obtained in the form of function (34). It leads to solving a problem of the form:

$$\bar{a}^{(k+1)} = (\Gamma^T \cdot \Gamma)^{-1} \cdot (\Gamma^T \cdot \bar{v})$$
$$\left(\overline{\Gamma^T}\right)_j = \left[1, (jt)^2, (jt)^3, \cdots, (jt)^k\right] \qquad (35)$$

From here follows, that in a sliding mode of time on an interval $(t_i \cdots (t_i + \Delta t))$, the parameters of computing stability, for example, the characteristic of conditionality [3] or value of the determinant are functions of time of the process of aircraft takeoff run:

$$Cond\left|(\Gamma^T \cdot \Gamma)\right| = f_1(t_i)$$
$$\det\left|(\Gamma^T \cdot \Gamma)\right| = f_2(t_i) \qquad (36)$$

They can vary in an unpredictable way, and, consequently, it is necessary to apply special measures for the stabilization of computation. The dependence (32) was calculated for the parameters:

$$a := \begin{pmatrix} 0.1 \\ 0.07 \end{pmatrix} \omega := \begin{pmatrix} 0.21 \\ 2 \end{pmatrix}$$
$$\alpha := \begin{pmatrix} 1 & 0 \\ 0.1 & 0.21 \\ -0.0341 & 0.042 \\ -0.01223 & -0.00296 \\ -0.0006 & -0.00286 \end{pmatrix} \qquad (37)$$

Here the second coefficients of the vectors a and ω have been used for modelling the occurrence of short-term changes in the aircraft engine thrust. Coefficients of the vector α characterize the dependence of the derivatives on the function (32). The Fig. 1 and Fig. 2 show the change of speed of the aircraft within 12 seconds of the start until the moment of liftoff from the runway. In the Fig. 2 the effect of the short-term changes in the aircraft engine thrust on the aircraft speed is shown.

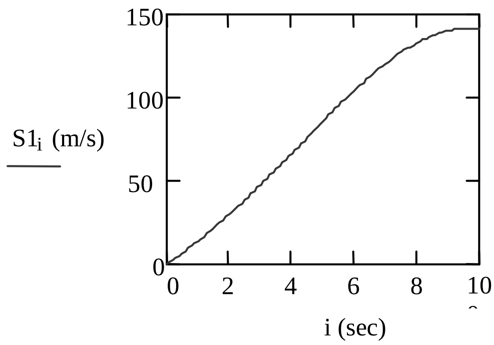

Fig. 1. Dependence of the aircraft speed from time

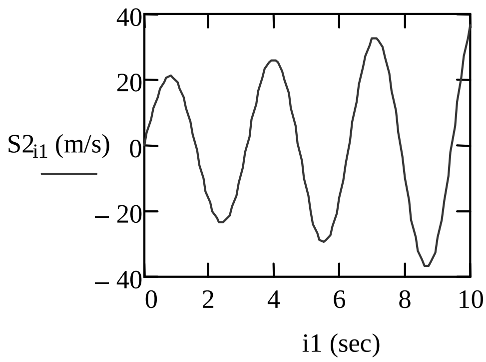

Fig. 2. Perturbations caused by the work of the aircraft engine (dependence of the change of aircraft speed from time)

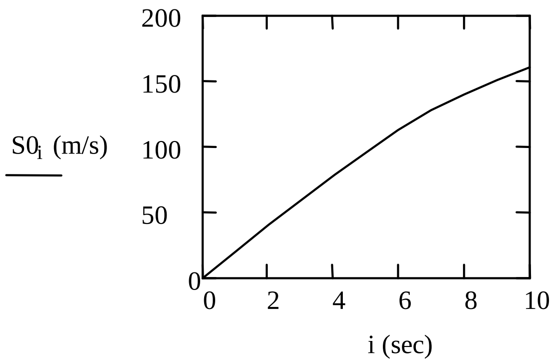

Fig. 3. The filtered signal of the aircraft speed

TABLE 1
THE DEPENDENCE OF ERRORS OF DERIVATIVE CALCULATION FROM THE DISTANCE TRAVELED FOR 10 SECONDS

	ϕ4 (t)	ϕ5 (t)	ϕ6 (t)	ϕ7 (t)	ϕ8 (t)
$\delta\%\left(x(t)^{\langle 1 \rangle}\right)$	3.757	0.2711	0.0157	0.0061	0.1968
$\delta\%\left(x(t)^{\langle 2 \rangle}\right)$	32.26	4.7295	0.4295	0.0411	0.0706
$\delta\%\left(x(t)^{\langle 3 \rangle}\right)$	3343.7	295.5063	36.3638	3.3328	3.2004
$\delta\%\left(x(t)^{\langle 4 \rangle}\right)$	4990.5	1314.0096	167.6249	25.8745	3.2004
$\delta\%\left(x(t)^{\langle 5 \rangle}\right)$	42608.5	9580.5455	3304.3595	377.3578	84.8902

In Fig. 3, the filtering properties of algorithm are shown. The calculated characteristic practically coincides with that shown in Fig. 1. It demonstrated that the short-term changes in engine thrust were not critical and could be caused by small deviations in the fuel dosing equipment in the aircraft engine.

The percentage of RMS of the errors of derivative calculation within 10 seconds are shown in the Table 1. From the data in the table follows, that the 4th order derivative can be determined within 3% using the function (34) of eighth order.

IV. Conclusions

The new information technologies based on the use of symbolical combinatory computing models allow to create parallel algorithms for identification of dynamic characteristics of technical objects. In this case, it is possible to use high-performance computers, working in parallel modes, for processing the flight information at the aircraft flight test stage. The increase in performance of onboard computers allows to use more advanced algorithms for the control of aircraft takeoff run. Parallel algorithms can be created on the basis of graph structures. They possess hierarchical structure and can be represented in the form of decomposition into independent fragments. It allows to improve the usability of algorithms for solving ill-conditioned systems of equations and to increase their noise tolerance.

Use of the offered new information technologies allows to gather additional valuable information about the aerodynamic characteristics of the aircraft and about the characteristics of its equipment. It will not require the use of any expensive hardware. All advantages are achieved due to the use new algorithms and software in the onboard computers. It allows to reduce the duration of flight test cycle and to reduce the expenses related to the development of new aircraft designs.

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Jānis Grundspeņķis, Genādijs Burovs. Informācijas tehnoloģijas lidmašīnu eksperimentālo modeļu testa lidojumiem paredzēto algoritmu un programmatūras izstrādei
Rakstā apskatīta iespēja izmantot jaunas informācijas tehnoloģijas signālu apstrādei lidmašīnu testa lidojumu laikā. Tā kā lidojuma režīmiem ir spēkā stingri ierobežojumi, lidmašīnas un tās aprīkojuma parametru identifikācija tiek veikta situācijā, kurā dinamiskie raksturojumi ir grūti novērojami. Tas apgrūtina veiktspējas nodrošināšanu skaitļošanas algoritmiem, kas paredzēti no lidojuma parametriem veidoto vienādojumu sistēmu atrisināšanai. Tradicionālie algoritmi

balstās uz darbību secīgas izpildīšanas principiem tādēļ tiek apskatīta iespēja izmantot jaunas informācijas tehnoloģijas algoritmu ar paralēlu struktūru radīšanai. Tas ļautu izmantot paralēlos datorus un palielināt informācijas apstrādes ātrumu. Tādā gadījumā būtu iespējams izmantot efektīvākus algoritmus bīstamo lidojuma režīmu vadībai. Rakstā šis uzdevums tiek risināts lidmašīnas ieskriešanās pirms pacelšanās gaisā procesam. Jaunās informācijas tehnoloģijas piedāvāts realizēt uz simbolisko kombinatorisko skaitļošanas modeļu pamata.

Янис Грундспенькис, Геннадий Буров. Информационные технологии создания алгоритмического и программного обеспечения летных испытаний самолетов
Исследуются возможности использования новых информационных технологий для обработки сигналов на этапе летных испытаний самолетов. Поскольку на полетные режимы накладываются летные ограничения, идентификация параметров самолета и его оборудования осуществляется в условиях плохой наблюдаемости динамических характеристик. Это усложняет задачу обеспечения работоспособности вычислительных алгоритмов решения систем уравнений, формируемых по результатам измерений полетных параметров. Традиционные алгоритмы основаны на последовательном принципе выполнения вычислительных операций. Поэтому исследуется возможность применения новых информационных технологий для создания алгоритмов с параллельной структурой. Это позволит применить параллельные ЦВМ и увеличить скорость обработки информации. В этом случае имеется возможность применить более совершенные алгоритмы управления опасными режимами полета. Такая задача решается для режима разбега самолета при взлете. Новые информационные технологии предлагается реализовать на основе символьных комбинаторных вычислительных моделях.