ROCKET-SPACE DEVICE ENGINEERING AND INFORMATION SYSTEMS
Vol. 7, Iss. 4, 2020, pp. 2–12

Refinement of the Matching Coefficients of the Mathematical Model of Spacecraft Motion Using the Concept of "Generalized Observability"

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Abstract. The aim of this paper is to improve the scientific and methodological support of identification tasks when specifying the parameters of spacecraft motion. The article examines a systematic approach to ensuring the specification of the ballistic coefficient in the mathematical model of the spacecraft motion. For emergency situations, an approach was used that takes into account the object-system "task-solution tool", which allows taking into account the errors of all elements of the navigation tool. The introduced structural property "generalized observability" makes it possible to solve the problem of Sb refinement in traditional and non-traditional conditions in the practice of operational navigation and ballistic support of spacecraft flight.

Keywords: spacecraft, mathematical model of motion, ballistic coefficient, generalized observability, navigation and ballistic support

Introduction

Improving the accuracy of predicting the motion of spacecraft (SC) requires matching the mathematical model of motion and, in particular, the model of the atmosphere or light pressure, with experimental data. To solve this problem, the ballistic coefficient (S_δ) or the coefficient(s) of the light pressure are often used, which in this case act as the matching coefficients [1,4].

Further, the questions of clarifying the matching coefficients (MC) used in mathematical models of motion (MMM) of spacecraft will be carried out using the example of refining the ballistic coefficient. In this case, some inaccuracies in the knowledge of other parameters of the SC MMM during the refinement of S_δ according to the measurement data (identification of the SC MMM) will flow into the refined ballistic coefficient.

A similar situation is, for example, when specifying the coefficient of light pressure relative to ignorance of the parameters of the atmospheric model. In this case, the inaccuracies of the mathematical description of the atmosphere flow into the adjusted coefficient of light pressure, which at this stage serves as the matching coefficient of the spacecraft SC MMM. A similar situation arises with respect to other specified parameters, namely: parameters of optimization of the corrective propulsion system, taking into account various kinds of disturbing forces, etc.

Ballistic coefficient refinement techniques used in practice

The condition for the equality of the real and simulated acceleration when refining the ballistic coefficient is the expression:

$$\rho S_\delta = \rho_m S_m, \quad (1)$$

where

ρ is the real density of the atmosphere,

S_δ is the ballistic coefficient,

ρ_m is the simulated density,

$S_м$ is the simulated ballistic (matching) coefficient.

This relationship is valid only for low-orbit objects, the speed of which is determined relative to the atmosphere and the unaccounted for disturbances are mainly due to insufficiently accurate modeling of the atmospheric density.

In most cases, the modeled deceleration acceleration includes a part of the accelerations from other forces that were not taken into account by the model of spacecraft motion. At altitudes of more than 400 - 500 kilometers, where the disturbances from atmospheric braking can be comparable with other disturbing factors unaccounted for in the mathematical model of motion (MMM), methods for refining S_δ based on condition (I) often turn out to be false.

The choice of the S_δ refinement method and interval depends on many factors and, first of all, on the average flight altitude, geoheliophysical parameters, and the accuracy of determining the orbit. The issue of reducing the influence of errors in determining the orbit of the spacecraft is associated with the need to increase the refinement interval S_δ. An increase in the refinement interval, in turn, leads to the leveling of new data on the atmosphere, which increases the errors in predicting the movement of objects. In addition, the value of the refinement interval S_δ for each type of spacecraft is associated with the adopted ballistic support scheme.

Thus, the method and interval of S_δ refinement for different types of spacecraft can vary within wide limits. Intervals that are usually chosen: several revolutions (3-8 hours), 1 day, 1 week, 4-5 weeks.

An interval of several revolutions is used when introducing the ballistic coefficient into the number of refined parameters of the problem of determining the state vector of objects.

The daily refinement interval S_δ is usually used for ballistic support of a spacecraft with flight altitudes of 200-400 kilometers.

Weekly and monthly intervals of S_δ refinement are used for objects with a minimum flight altitude of 500-800 kilometers.

At altitudes of more than 400-500 kilometers, depending on the geo-heliophysical conditions and the adopted model of motion, along with the ballistic coefficient, it is advisable to refine other matching coefficients (for example, coefficients that take into account the light pressure).

Consider the most common ways to refine S_δ [1-3, 5].

Typical and special methods for specifying the ballistic coefficient in the practice of operational navigation and ballistic support (ONBS) are given in Table 1.

Table 1. Typical methods for refining the ballistic coefficient

No.	Typical and Special Methods for Refining Sδ	Formal description	Note
1.	Choosing S_δ as the mean of the observed values		The method has shown good results in predicting spacecraft motion in near-circular orbits with flight altitudes of 200-300 km.
2.	Method of S_δ refinement by predicting changes in the orbital period	$S_{\delta j=}S_{\delta j\text{-}1}\dfrac{T_N-T_{N+n}}{T_N-T^{pr}_{N+n}}$	The adjusted value of S_δ is proportional to the ratio of the real and predicted changes in the circulation period
3.	Method of S_δ refinement by error in predicting the time of exit to the equatorial plane	$S_{\delta j}= S_{\delta j\text{-}1}\dfrac{t_N+T_N n-t_{N+n}}{t_N+T_N n-t^{pr}_{N+n}}$	S_δ is refined by the error in predicting the time of entering the equatorial plane
4.	Method of S_δ refinement by temporal errors of measurement sessions	$\Delta S_\delta=-\dfrac{4}{3}\dfrac{a}{a'}\dfrac{\Sigma\ \delta t_i(t_i-t_0)^2}{\Sigma\ (t_i-t_0)^4}$	t_0 is the time of the specified initial conditions of motion, a is the major semi-axis of the orbit, a' is the rate of change of the major semi-axis under the influence of the atmosphere at S_δ=1, N is the number of observation sessions
5.	Method for S_δ refinement based on major semi-axis prediction error	$S_{\delta j=}\ S_{\delta j\text{-}1*}$ $\dfrac{\Delta a(a_n^2-a_n\ a^{pr}_{N+n}+a^{2pr}_{N+n})}{\Delta a^{np}(a_N^2-a_N\ a_{N+n}+a^2_{N+n})}$, $S_{\delta j=}\ S_{\delta j\text{-}1*}$ $\dfrac{\Delta e(2a_Ne_N+a_Ne^{pr}_{N+n}+a^{pr}_{N+n}\ e_N+2a^{pr}_{N+n}\ l^{pr}_{N+n})}{\Delta e^{pr}(2a_Ne_N+a_Ne_{N+n}+a_{N+n}\ e_N+2a_{N+n}\ l^{np}_{N+n})}$ where $\Delta a=a_N-a_{N+n}$ $\Delta a^{pr}=a_N-a^{pr}_{N+n}$ $\Delta e=e_N-e_{N+n}$ $\Delta e^{pr}=e_N-e^{pr}_{N+n}$ $a_N, e_N, a_{N+n,}\ e_{N+n}$ *are the* values of the semi-major axis and eccentricity at the beginning and end of the refinement interval; $a^{pr}_{N+n}, e^{pr}_{N+n}$ – predicted at the end of the interval of refinement of the values of the semi-major axis and eccentricity.	The formulas (like all of the above methods) give an a posteriori estimate of the value of the ballistic coefficient.

No.	Typical and Special Methods for Refining Sδ	Formal description	Note
6.	A method for refining S_δ by statistical processing of the results of solving the problem of determining the state vector on 3-6 consecutive revolutions	$\Delta t_i \approx \frac{\partial t_i}{\partial S}\Delta S \quad \frac{\partial t_i}{\partial S} \approx \frac{\Delta t_{i2} - \Delta t_{i1}}{\Delta S}$, $\Delta S = \frac{\Sigma\, \Delta t_i \frac{\partial t_i}{\partial S}}{\Sigma (\frac{\partial t_i}{\partial S})^2}$	$\Delta S_{\hat{e}} \quad \Delta S_{\hat{e}-1} \le \varepsilon$ For a more accurate finding of the value ΔS, the solution of the OVS problem and the calculation of $\frac{\partial t_i}{\partial S}$ can be repeated several (k) times until the condition is satisfied
7.	Method of S_δ refinement in the interval of (4-5) weeks	$S_\delta = S_1 + \Delta S$, S_1 is an approximate value of the ballistic coefficient, $\Delta S = \frac{\Sigma\, \Delta t_i \frac{\partial t_i}{\partial S}}{\Sigma (\frac{\partial t_i}{\partial S})^2}$ (see method 6).	The method is applicable for a spacecraft with a perigee of up to 600-800 km in a calm geoheliophysical environment
8.	A way to refine S_δ by minimizing the functionality	The solution to the problem of determining the state vector by the least squares method is usually reduced to minimizing a functional of the form: $F(q, S) = [h - h(q, S_\delta)]^T P [h - h(q, S_\delta)]$ *Where h is the vector of measurement results, $h(q, S_\delta)$ is the vector of calculated values of the measured parameters, q is the calculated value of the vector of initial conditions, P is the diagonal weight matrix. Or* $F(S) = [h - h(q^*, S)]^T P [h - h(q^*, S)]$, *where q * is the estimate of the vector of initial conditions. The change in the functional is approximated by a polynomial of the second degree. Based on this, to find the minimum, it suffices to calculate three values of the functional $F_0(S_{\delta 0})$, $F_1(S_{\delta 1})$, $F_2(S_{\delta 2})$ on condition of $S_1 = S_0 + \delta S$ $S_2 = S_0 - \delta S$.* $S^*_\delta = S_0 + \frac{\delta S (F_2 - F_1)}{2(F_2 + F_1 - 2F_0)}$	When predicting motion in the interval of 12-14 orbits, the S_δ refinement method shows the best results.

No.	Typical and Special Methods for Refining Sδ	Formal description	Note
9.	S_δ refinement method based on secular variation of the major semi-axis of the orbit	The mathematical model of motion, built according to the averaging scheme, allows for the error in predicting motion along the orbit to write the expression $\delta t = -\frac{3}{4}\frac{\grave{a}'\Delta t^2\ \delta S_\delta}{\delta S_\delta}$. From here, the correction to the ballistic coefficient is determined	$\grave{a}'$ is the value of the derivative of the major semi-axis in the right parts of the system of averaged DE, Δt is the motion prediction interval
10.	Refinement of the ballistic coefficient for a given mathematical model of motion (the more accurate is the MMM, the higher is the efficiency of the method).	$\Delta S_{\delta i} = \beta_i \left\lvert \delta t_{\acute{y}i} \right\rvert$ The first factor is: $\frac{k_1}{\Delta N_i^2}$. $\Delta S_{\delta i,0} = \frac{k_{1,0}}{\Delta N^2}\ \delta t_{\acute{y}}\ \frac{S_{\delta i,0}}{S_{\delta i}}$	β_i are the proportionality coefficients (i= 1,..,n), $\Delta S_{\delta i}$ is the relative change in $S_{\delta.}$

From a theoretical point of view, the considered methods of determining the ballistic coefficient in the MMM of a spacecraft refer to various methods (often techniques) for solving parametric identification problems, one of the important approaches of which is the use of the state vector of complex dynamical systems. In particular, an identifiable parameter being refined (for example, S_δ) can be introduced into the estimated spacecraft state vector based on measurements of the current navigation parameters (MCNP), and the parameters of the initial conditions of spacecraft motion and the required coefficient are simultaneously refined from the available volume of the measurement sample. This approach has a significant **drawback for a small fixed sampling** with various measurement errors (including anomalous ones), since the estimation accuracy of each of the determined parameters deteriorates with the expansion of the state vector. In addition, the potential errors in determining the elements introduced into the state vector may turn out to be excessively large for further use in the spacecraft MMM.

The description of the spacecraft MMM should use the structure and parameters, the values of which are obtained much more accurately than the data that are calculated in the process of applying the mathematical model. For example, the coefficients of the Earth's gravitational field model must be determined in advance with a high degree of accuracy to solve various problems of predicting the parameters of the motion of the objects under study.

The matter becomes more complicated if inaccurate (or even rough) characteristics (parameters) are used in MMM. For example, inaccurate knowledge of the ballistic coefficient or the coefficient of light pressure in the model of spacecraft motion with a sufficiently accurate setting of the input refined parameters or initial conditions (IC of motion) makes this **MMM unproductive**. It can only be used to assess the characteristics of a certain class of spacecraft with hypothetical initial data.

The methods for refining the ballistic coefficient given in Table 1 do not use the principle of additional expansion of the state vector for the simultaneous refinement of the identified parameter S_δ

and the spacecraft state vector (for example, the initial conditions of motion), and, as a rule, methods of a repetitive (iterative) mode of sequential refinement of S_δ are used with its further use to improve the accuracy of the spacecraft state vector and the subsequent solution of target problems with the greatest effect.

The described sequential computational procedure may not converge to the true (or acceptable value) when refining the ballistic coefficient for various types of spacecraft orbits with individual requirements for the accuracy of calculating the IC of the motion and various MMMs used.

*A **fundamental problem** arises - how to proceed in this specific case: is it more efficient to calculate S_δ (or other identification parameters) by expanding the spacecraft state vector with simultaneous refinement of the IC of motion (or other extended state vector), or apply the described iterative procedure using, for example, the methods presented in the table? In addition, an additional question arises: which of the described options for solving the problem is advisable to use?*

The practice of operational navigation and ballistic support of spacecraft flights shows that in some cases the first of the considered identification approaches is quite effective and reliable if the second is not used satisfactorily and, conversely, in other cases only the second approach turns out to achieve the goal of the calculations.

The use of generalized structural properties of measurement problems when refining the ballistic coefficient.

One of the options for solving the problem can be an approach using the structural properties of measurement problems, namely, using the original concepts of generalized observability and (or) generalized identification of the considered system of navigation-ballistic support for spacecraft control at the stage of flight tests and operation.

Before the general formulation of the problem, which makes it possible to develop recommendations for the determination (refinement) of S_δ in each specific case, note a number of **factors affecting the magnitudes and values of the ballistic coefficient**. These factors include:

- the used mathematical **models of the spacecraft motion**, the composition and accuracy of the description of the disturbing factors described by the spacecraft MMM;

- **the nature of the change (osculation) of the orbit** (eccentricity, semi-major axis, etc.) and the **spacecraft flight altitude**;

- **the area of the midsection** and the dynamics of its change (design parameters and operating technologies);

- **the state of solar activity** and its variations in a specific period;

- **volume and measurement errors** of current navigation parameters (MCNP);

- **intervals of refinement** of the matching parameter-ballistic coefficient (several revolutions, daily, weekly, monthly);

- **mathematical methods of processing** MCNP when determining (refining) S_δ with the inherent calculation errors in the adopted models;

- **the required calculation accuracy**, which depends, first of all, on the specified accuracy of the calculation of the initial conditions of the spacecraft motion, and some other characteristics.

Each of the factors presented includes a whole range of possible options for using models, methods, conditions, data, and requirements in the NBS practice. Specifically, the key factors noted above are transformed into hundreds of options and elements of the software and mathematical support of the automated NBS system, which must be analyzed, calculated and justified for the application in the conditions of operational navigation and ballistic support of spacecraft control.

Part of such analysis and calculations is performed in advance (a priori), and part directly during the work of the NBS in an on-line mode.

The list of features of the solution of the problem shows that it should be solved in a **stochastic (probabilistic) setting and (or) using fuzzy information about sets with the assignment of membership functions**. The rich experience of practical solutions suggests the need to use **an intellectual (natural and (or) artificial) component** in calculations within the automated software package (ASP) of the NBS.

Further, to solve the problem of generalized identification of the ballistic coefficient, you can use several techniques (which were mentioned above): identifying the possibility of its determination by expanding the vector of the estimated state of the spacecraft or choosing a method for estimating S_δ, for example, one of the above methods, which also needs to be justified sometimes in an operational mode.

Studies show that to implement the first approach, it is advisable to use the so-called **information derivative** introduced in [8], from the physical point of view, operating with the change in information before and after the reference mapping, and the second - using singular ultraoperators that also perform intellectual work.

Let us consider in more detail a singular ultraoperator (**classifier-recognizer**) called a general classifier, which can, on the basis of an intelligent approach, prompt in an automated mode which of the methods of specifying the ballistic coefficient is expedient to use in a particular case. Calculations made in this way will provide a reliable solution to the problem as a whole.

The commutative diagram of a singular ultraoperator $\check{E}$ in general view is shown in Fig. 1.

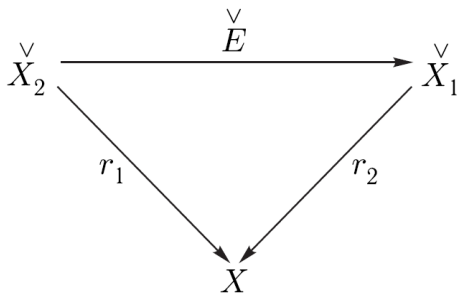

Fig. 1. General view classifier diagram

Among singular ultraoperators (classifiers), translators are distinguished, as well as generalizing, refining and general classifiers [8]. Based on the logic of the problem being solved in the considered technological operation of the NBS, it is advisable to apply, as noted, the **classifier-recognizer** presented in the required notation in Fig. 2.

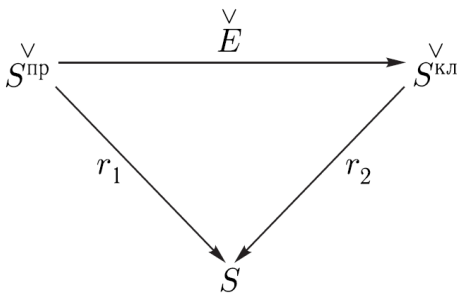

Fig. 2. Diagram of a singular ultraoperator (classifier) of problem of the refinement of S_δ

In fig. 2, the following notation is used:

$\check{S}^{pr}$, $\check{S}^{cl}$ - two ultrasets of one object - ballistic coefficient S;

$\check{E}$ - ultramapping (ultraoperator) over the support operator (in this case, singular);

$r_1 : \check{S}^{pr} \rightarrow S$ - a projection operator who assigns a point to a flattening. The operator r_2 is defined similarly.

For a compact recording of the ultraoperator (UO) using the **attributes** of the tool task-tool solution (object-system) and **classes** (formulas for calculating the ballistic coefficient), we will use the following notation in the equipments:

- a set of attributes of the object-system toolkit (Table 3.2) that have a fundamental impact on the accuracy of calculations - a, b, c, d, e, f, g, h;

- a set of classes (methods) for assessing S_δ (table 3.3) - 1,2,3,4,5,6,7,8,9,10.

Table 2. Elements of equipping a set S with the use **of features** task-solution tool (object-system) $L^{ïð}$.

	Feature lattices (object-systems)	**Scales**
a	Algorithms of the mathematical model of spacecraft motion (systems of differential equations - SDE MMM SC spacecraft)	α_1
		$\alpha_1^{\bullet}$
b	Characteristics of changes (osculation) of the spacecraft orbit and altitude	α_2
		$\alpha_2^{\bullet}$
c	Midsection area and dynamics of its change	α_3
		$\alpha_3^{\bullet}$
d	Solar activity state	α_4
		$\alpha_4^{\bullet}$
e	Measurement volume and errors	α_5
		$\alpha_5^{\bullet}$
f	Refinement intervals of the matching parameter-ballistic coefficient	α_6
		$\alpha_6^{\bullet}$
g	Mathematical methods for processing ITNP	α_7
		$\alpha_7^{\bullet}$
h	Required calculation accuracy (NU and S_δ)	α_8
		$\alpha_8^{\bullet}$

Let us write down two framings of the support set S [6-9]. The first equipment is introduced with the following features:

$$\check{S}^{pr} = P \times L^{pr} \times S,$$

here P is an elementary (binary (0,1)) ER reliability lattice.

Moreover, the signs are set by a **scale** showing which elements of the instrument are suitable for a specific use in calculating S_δ:

$$L^{pr} \supset S,$$

$$L^{pr} \supset S = \{\alpha_1, \alpha_1^{\bullet}; \alpha_2, \alpha_2^{\bullet}; \ldots, \alpha_8, \alpha_8^{\bullet}\},$$

$$L^{pr} = L_1 * L_2 * \ldots * L_8.$$

On the right side of the last expression, the signs L_1 have a lattice with parameters $\alpha_1, \alpha_1^{\bullet}$ taking the values "yes" - "no", i.e. whether this element of the tool is suitable for performing calculations for the required refinement of S_δ or not. Similar grids have other features $L_2, \ldots, L_8$ (i.e., other elements of the calculation tool).

The second ultra-equipment is filled with classes (i.e. possible methods of calculating of S_δ). Above, we used well-known and original 10 calculation methods that have proven themselves in practice of NBS. Of course, other additional algorithms for calculating S_δ can be added to the proposed methods.

$\check{S}^{cl} = P \times L^{cl} \times S$, $L^{pr} \supset S^{cl}_{\grave{A}\grave{O}}$, the index AT means atomic [4], i.e. a specific method for calculating S_δ.

In our case

$$\emptyset^{cl} \supset \quad {}^{cl}_{\grave{A}\grave{O}} = \text{ùùùùùù}$$

Before proceeding directly to the formation of the kernel-table of the classifier-recognizer, it is necessary to pay attention to the **canonical ICs** introduced in [1,4], for which the condition of homomorphism of lattices of properties is satisfied. In this case, it is possible to specify the reflection of properties not on the entire lattice $\check{S}^{i\,\partial}$, but only on a limited basis. As such, this limited basis is described above. For example, the algorithms of the mathematical model of spacecraft motion fall into tens to hundreds of variants associated with the possibilities of using numerical, analytical, numerical-analytical MMM of the spacecraft, using various kinds of variables (Cartesian or Keplerian coordinates, non-singular variables, etc.), taking into account the use in the right-hand sides of systems of differential equations (SDEs) of a diverse spectrum of disturbing forces in one form or another (one-parameter or spatial in different coordinate systems), using different reference epochs, etc. The algorithmic description of the models of the same disturbing forces can differ greatly from each other, just as, for example, the methods of numerical integration in unified numerical SC MMM can be different with their specific calculation errors. These remarks can be continued.

Table 3. Elements of set equipment S with the use of **classes** (formulas for calculating the ballistic coefficient) L^{cl}.

	Class lattices
1	Choosing S_δ as the mean of the observed values
2	Method of S_δ refinement by predicting changes in the orbital period
3	Method of S_δ refinement by error in predicting the time of exit to the equatorial plane
4	Method of S_δ refinement by temporal errors of measurement sessions
5	Method for S_δ refinement based on major semi-axis prediction error
6	A method for refining S_δ by statistical processing of the results of solving the problem of determining the state vector on 3-6 consecutive revolutions
7	Method of S_δ refinement in the interval of (4-5) weeks
8	A way to refine S_δ by minimizing the functionality
9	S_δ refinement method based on secular variation of the major semi-axis of the orbit
10	Refinement of the ballistic coefficient for a given mathematical model of motion

The morphological scheme of measuring tasks [1,4] gives not only a classification of measuring tasks, but also studies mathematical models of measurement processes with consideration of:

- **systematic (singular)** components $\vec{h}_{sys}(t)$ due to incompleteness of taking into account some important factors in the measurement equations, which leads to a smooth, monotonic nature of this error;

- **random (regular)** components $\vec{h}_{rand}(t)$ caused by not taking into account secondary factors (for example, fluctuations in atmospheric parameters, thermal noise and vibrations in measuring equipment, etc.), which are usually represented by random processes and quantities;

Table 4. An example of constructing a typical abbreviated version of the kernel-table of a singular ultraoperator for an ERS SC

The elements UO	Content of elements	Note
A	$1 \mapsto 1$	
B	$\alpha_1 \mapsto 2 \cup 3 \cup 4 \cup 5 \cup 8 \cup 9 \cup 10$	Analysis of an element of the object-system of the NBS for solving the problem of refining S_δ: **variants of algorithms of CS MMM**
	$\alpha_1^\bullet \mapsto 1 \cup 6 \cup 7$	
	● ● ●	
	$\alpha_7 \mapsto 5 \cup 6 \cup 7$	Analysis of an element of the object-system of the NBS for solving the problem of refining S_δ: **methods of processing MCNP** 1,2,3
	$\alpha_7^\bullet \mapsto 1 \cup 2 \cup 3 \cup 4 \cup 8 \cup 9 \cup 10$	
	● ● ●	
E	$S \mapsto S$	

- **abnormal (gross)** errors $\vec{h}_{an}(t)$ that appear as a result of equipment malfunctions or incorrect operator actions. Usually it is modeled by separate rare outliers. In the practice of flight tests (FT), the content of abnormal errors can range from 7 to 20%.

Methods for combining measurement errors (additive, multiplicative, combined) play a special role.

Similar remarks are related to other elements of feature lattices. All of them must be carefully analyzed and investigated, as a rule, before operational work at the design stage of the considered intelligent NBS system.

Thus, when using canonical ultraoperators, not only the dimensions of arrays for storage in a computer are reduced, but also studies of the volumes of interaction with variants of methods for determining matching parameters are reduced.

Based on the remarks made, it is possible to form a core-table of the classifier-recognizer. Table 4 shows an example of constructing a typical abbreviated version of the singular ultraoperator table-kernel for studying spacecraft flight.

Legend to table 4:

Column-row **A** means the transition of true information into true reliability of the UO.

Row **B** means displaying various property grids.

Row **E** means the transition of one object to another (in this case - the identical operator - the ballistic coefficient).

The classifier-recognizer $\check{E}$ gives recommendations to the ballistic operator (or to the automated control system of the NBS processes) on the choice of several (or even only one specific method) options for specifying the ballistic coefficient.

At the same time, it may seem that this core-table has the meaning of a table of simple correspondence: there is an object-system, including, among other things, elements of the tool of possible solutions and various ways of finding matching parameters. However, the found classifier-recognizer has a broader function and is an intelligent means of matching and finding the required solutions.

A detailed description of the classifier-recognizer leads to the analysis of a huge number of options that fundamentally allow solving the problem, but will not be able to provide, for example, the specified accuracy or the fulfillment of other conditions and requirements. When searching for the best solution, the emergence property of the system can fully work, when a simple consideration of an additional factor, for example, in the spectrum describing disturbances in the SC MMM, will fundamentally improve the output result. The task

becomes much more complicated when considering an object-system of an extended composition, when this concept includes external factors, such as, for example, the requirements for the speed of calculations or changes in the process of work associated with the final accuracy of determining the calculated parameters. A similar situation arises when determining anomalous measurement sessions among the volume of received MCNP.

Conclusion

As a practical example, let us note an important case that demonstrates the above circumstances. An important method for determining the ballistic coefficient for low-orbit spacecraft is the method for specifying S_δ by the error in predicting the change in the orbital period (option 2 of Table 1). Usually, for an ERS spacecraft with flight altitudes in circular orbits about 200 - 250 km, the change in the semi-major axis of the orbit due to atmospheric drag can be 800 - 1500 m per day (about 17 flight orbits), and for spacecraft with heights of 1000 - 1100 km about 5 m also due to the resistance of the atmosphere per day of flight. Another fact: in the first case, due to not taking into account the tesseral and zonal (except for the compression of the Earth, harmonic 2.0) harmonic components in the model of the Earth›s gravitational field (EGF), inaccuracies in the description of the semi-major axis, affecting the inaccuracy of the description of the draconian period, can amount to 150-200 m. Therefore, the considered formula for specifying the ballistic coefficient works quite well even under the conditions of taking into account only disturbances from the Earth›s compression and the static model of the atmosphere in the case of non-obstructive equipment of the first type of spacecraft under consideration with flight altitudes of 150-200 km, since a significant effect on the magnitude in the calculation The S_δ of the draconic period used is caused by the resistance of the atmosphere.

For the second type of the spacecraft under consideration, not taking into account (or insufficiently taking into account the influence of harmonic components in the EGF model in the spacecraft MMM) leads to an uncertainty of hundreds of meters per day of flight in determining the semi-major axis, which, in comparison with the influence of the atmospheric drag of 5 meters, makes the formula considered in Approach 2 to refine S_δ completely untrue. This is a vivid example of the fact that the estimate of the obtained ballistic coefficient as a matching parameter will correspond to the considered conditions of the problem, but is completely inapplicable, for example, to predicting the process of spacecraft motion, which is calculated using other values included in the prediction of spacecraft motion by formulas.

The output for determining the estimate of the ballistic coefficient for the considered error in predicting the change in the period of revolution for the second type of spacecraft is as follows. The MMM of the spacecraft should take into account the corresponding zonal and tesseral harmonic components in the model of the Earth›s field (for example, up to about 8.8). In this case, the formula for calculating S_δ becomes inoperative. To eliminate this fact, it is advisable to subtract from the estimate of the value of the draconic period of its perturbation due to changes in the semi-major axis by the harmonic components of the Earth›s field.

These conclusions were made using detailed descriptions of classifiers-recognizers for a variety of mathematical models of spacecraft motion.

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