Technology of spacecraft on-board equipment design support

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Abstract. The Technology is shown that combines knowledge bases, information and graphic resources into a set of automated software tools. Technology includes the methods of intellectual models’ building and the tools of scenario creation for measurement, data transmission, test results’ control and visualization. It is implemented in the software-mathematical model of the on-board equipment control system and the software of the testing equipment. Software is integrated into a technological platform for the design and testing of technical systems. Application of Technology reduces the time of the on-board equipment design and production, reduces import dependency of Russian space development and increases its competitiveness in the space systems’ market.

1. Introduction
Increase of the efficiency of space equipment production demands creation of new technological approaches providing digital automated support of the processes of designing and testing of spacecrafts’ on-board equipment. There are developed the methods and approaches of serial production automation, however lack of the universal design solutions and unified protocols of informational interaction of new elements of the on-board equipment makes it difficult to create and implement typical software means.

At present, there is a good scientific start determining creation of informational and functional approaches to the support of space systems’ design: Eickhoff J., Strzepek A., Millet B., Darnes H., Zeigler B. etc. [1, 2]. Software infrastructures are being created, they are based on the technology of simulation modeling providing support of construction at different stages of the production life cycle from the design solutions at a design bureau level and up to test preparation and conduction on hybrid test stands. Examples of infrastructural approaches are highlighted in the publications of Liu Y., Hu X., Arguello L., Cohen L., Mollier A. etc. [3-5]. Methods of building and usage of simulation models on the basis of artificial intellect, ontologies and knowledge bases are actively developed, including the works of Hennig C., Viehl A., Eisenmann H. etc. [6, 7].

The review of application of the existing methods and technologies has shown that the support of task solution of real practical significance and complexity demands tightest integration of the artificial intellect paradigm with a whole number of methods, approaches and technologies from different areas, particularly with the automated systems of test preparation and conduction. Rational organization of the process of testing is a priority task aimed at production quality increase and cost reduction. In order to do testing, test complexes are built, special software systems of technological test control are developed providing tools for analysis of the on-board systems in standard and non-standard conditions of operation, supporting modeling of emergency situations including simulation of backup systems’ and communication channels’ failure. Although digital technologies are actively developed, the tasks of...
model construction and usage for test automation are not completely solved with the existing systems. It is necessary to create a unified end-to-end approach of digital support of complex technical systems’ production providing functional continuity of information resources and unification of software solutions. It should be based on intellectual methods helping to integrate all knowledge of the subject area for production and creation of companies’ information storage.

2. Issues of the automated of spacecraft’s equipment construction

Spacecraft’s equipment is a technical systems based on high-tech elements and software. A big influence on the processes of construction is caused by such issues as the significant number of components with many links, operation modes and control commands and also a complicated behavior that is hard to predict or describe analytically, as well as the high cost of errors and significant labor expenditures during experimental studies of the ready systems.

A constructor needs to create basic principles of interaction of the systems in accordance with different operational conditions and their purpose, and also to analyze both design solutions and the work of the created equipment. The result of the design is technical documentation including: technical specifications for components of the devices, telemetry and telecommands’ formats, transport and informational protocols, etc. On the bases of the documents prepared by the constructor, blocks of the equipment are manufactured. For big devices with a complex logics of operation, a company-manufacturer creates control-and-verification equipment and software that helps to conduct automated testing without connection of paired devices. Manufacturer’s control-and-verification equipment does not allow quality conduction of independent trials, because it demonstrates not the way the object of control corresponds with the constructor’s plan, but the view of the manufacturer on how it should work. Unrevealed errors lead to production cost increase and extend the time of the equipment’s production. In order to avoid this, the author suggests a new scheme of test organization including application of the methods basis of intellectual simulation models, the organization diagram of production processes is shown in figure 1.

![Figure 1](image_url)

**Figure 1.** Engineering, developing and testing support.

The new approach has been developed for universal software-and-hardware complex of the control-and-verification equipment. It allows to create command bases, models, specifications of the equipment and the knowledge base describing the modes of the equipment operation and the logics of interaction with paired devices at the stage of designing and then to use the created information resources for test
preparation and conduction. This approach helps to reveal errors in work of the objects of control at early stages, before manufacturing.

After the equipment has been tested offline, it is assembled in complexes of systems and comprehensive tests are being conducted. The new Technology provides the means of informational interaction between the object of control and the universal test complex which, in accordance with transport and information protocols, sends command packages, receives data and makes analysis of the devices functioning. At this stage, errors of the systems in a complex are detected. If problems are revealed, it is difficult to indicate exactly which of the complex’s devices is erroneous. Increase of the quality of offline testing due to new methods allows to minimize errors at final stages of testing, improves the quality equipment and it also reduces the time of production.

Thus, the new Technology rationalizes the processes of production and testing of the devices and allows to produce such quality improvements as reduction of duplicate functions and data streams, increase of clarity and efficiency test procedures and early detection of incompatibility of the built equipment with their specification. Besides, the suggested solutions comply with the existing architecture of companies, provide interfaces for exchange with different information systems and give possibility for migration of simulator, commands and telemetry structures from the existing systems.

3. On-board equipment construction support methods

In the basis of the new method of construction support lays the idea of an intellectual model of a spacecraft’s equipment operation simulation model. The model $S = <G, I, T>$ consists of graphical structure of configuration of the on-board systems – $G$ and the functional description – $F = \{V, R\}$, that includes virtual devices $V$ and condition-action rules $R$, allowing to simulate the work of devices in $T$ – moments of time [8].

The author suggests methods of intellectual models’ construction allowing to perform a targeted step-to-step designing of knowledge bases, analyze compliance of the structure with the model’s functional description, compare the work of the systems’ simulators with the results of spacecraft equipment testing. An example of the structure of a model for simulation of the command-software control of the systems is provided in figure 2. The model includes on-board systems, switching connections and interfaces for describing data exchange paths.

![Figure 2. The model’s structure.](image)

Study of the algorithms of a simulation model’s functioning helped to find the settings of the on-board systems’ simulators and to create on their bases the methods of tests’ creation. For test preparation and conduction the author suggests a formalized description of scenarios that are the methods of control, measurement, data transmission, the results’ visualization and control. The objective of the test is split into different subtasks including controlling and measuring actions. The actions are realized in form of virtual devices. The Technology is solving the tasks of syntactical control of the scenarios, provides
universality and extensibility of the device testing procedures, supports mechanisms of work with the onboard equipment’s simulators. The experiment organization scheme is provided in figure 3.

![Figure 3. Experiments organization scheme.](image)

The author suggests a complex of original methods of test procedures’ preparation and test analysis allowing to unite the methods of intellectual imitations, methods of measurement control automation and the analysis of the results of testing on the basis of the simulation model’s functioning precedents. The complex includes the method of test procedures’ generation that forms subset of knowledge base’s rules determining the work order of the ground and systems’ simulators during modeling of the control commands’ transmission. The chosen rules describe the sequence of data reception and transmission, as well as the criteria of the analysis of their completion. An important stage of test preparation and conduct is setting the criteria for the results’ assessment. The complex includes the method of the results’ analysis that has allowed to use the simulation modeling precedents for test automation. The result of the method’s performance are the precedents of the model corresponding with the telemetry of the on-board systems and the knowledge base’s rules describing the actions that led to specific values of the telemetry data’s parameters.

Implementation of the methods allowed to make analysis of characteristics of the studied objects at software models, and use them for creation of the methods of testing of real equipment and analyze the results of tests by comparing them with the simulation modeling precedents. The suggested approach considers all possible changes of the parameters in a simulation model and is used for different tests no matter what commands are sent to the object of control.

4. Implementation of the technologies for the support technical production

The new Technology is realized in a software complex that includes the SMM – Software and Mathematical Model of the on-board equipment of a spacecraft and the SCVE – Software for the Control-Verification Equipment [9, 10]. The created software complex provides a unified technological platform for end-to-end complex support of creation of the command-measuring systems of spacecraft.

Software SMM is installed at the constructors’ workplaces and allows to model functions of the on-board equipment, conduct simulation experiments, prepare tests, review and analyze their results, make reports. Software SCVE works as part of the control-verification equipment that includes measuring equipment for conduction of high- and low-frequency tests. During complex tests, SCVE performs interaction with an automated test complex located at the company-manufacturer of satellite systems. Each functional subsystem is a special tool corresponding with the modern requirements of software development. It provides advanced possibilities for solution of the tasks of modeling and analysis of the spacecraft’s on-board equipment operation supporting both autonomous and interactive step-to-step work mode. Application of the suggested methods and technologies for the design support provides higher efficiency of the processes of designing, development and testing of the systems of spacecraft’s. The scheme of basic functional subsystems – figure 4.
Integration and distribution of functional subsystems avoids duplication of software tools and data streams. The software allows you to build simulation models, create telemetry structures and command bases and use them to prepare tests and automate them. An example of software for control of on-board equipment is shown in figure 5.

The test methods are created from the simulation model, which describe the operating modes of the on-board systems. Thus, the software, built according to the Technology proposed by the author, allows:

- Create models of the devices function.
- Form a structure and graphic representation of the model for visualization and control of the designed methods of interaction of devices.
- Build scenarios and check them against the specification in the simulation model.
- Automatically create methods for command-program control from the knowledge base.
- Conduct experiments with telemetry monitoring and data visualization.
- Analyze device according to the specification in the model.
• Check command processing by checkpoints from test scenarios.
• Compare test results with simulation precedents.
• Generate reports with results.
• Maintain archives of experiments and reproduce them according to the data of the archives.

The estimated time to solve typical problems by a specialist is shown in Figure 6.

![Figure 6. Evaluation the time required for solution of tasks.](image)

The diagram shows the time required for tasks (1) creation of telemetry’s structure, (2) command CCU entry, (3) command OCS CU entry, (4) creation of test procedures, (5) choice of the parameters for tests using the methods of the new Technology – and without the use of specialized tools – . Due to the large number of commands and its necessary to determine and test them for the main and backup kits, the overall time of task solution increases proportionally to the amount of data.

The Technology allows to enter default values into the structure and determine the fields for which the value options are described in the structure. The suggested approaches have allowed to reduce the labor expenditures by 2-5 times on average due to test automation, generation of the procedures and use of the information resources. In the example, the time is calculated for one activity. With a large number of commands, the presence of basic and backup sets of equipment, different switching connections and the need to study various options for the interaction of systems, a significant reduction in time was obtained.

5. Conclusion
In this article described the Technology of on-board equipment design support that includes original methods of building intellectual models of simulation of the systems operation, methods of test automation, methods of creating of experiment procedures for the command-and-software control and the methods of analysis of the results of testing on the basis of simulation modeling precedents.

The suggested methods have been tested at a company-manufacturer of satellite systems and have proved their efficiency for reduction of the time of the on-board equipment’s design and production. Implementation of the suggested end-to-end digital technologies is an essential step to reduce dependency of Russian space developments on the import and to increase their competitiveness on the market of space systems.

References
[1] Eickhoff J 2009 Simulating Spacecraft System (Berlin: Springer)
[2] Strzepek A, Esteve F, Salas S, Millet B and Darnes H 2016 A training, operations and maintenance simulator made to serve the MERLIN mission Proc.14th Int. Conf. on Space Operations ed M Müller (NY: AIAA) p 1736-46
[3] Liu Y, Zhang L, Zhang W and Hu X 2016 An overview of simulation-oriented model reuse Theory, methodology, tools and applications for modeling and simulation of complex systems 646 48-56
[4] Arguello L, Miró J, Gujer J and Nergaard K 2000 SMP: A Step Towards Model Reuse in Simulation ESA Bulletin 103 107-11
[5] Mollier A, Cohen L and Vinay S 2015 SMP2 Modelling using the K2 Simulation infrastructure
Proc. Worksh. on simulation for european space programmes ed U Brauer et al (Noordwijk: ESTEC ) p 1-8

[6] Eito-Brun R 2016 Design of an ontologies for the exchange of software engineering data in the aerospace industry Comm. in Comp. and Inf. Science 649 71-8

[7] Hennig C, Viehl A, Kampgen B and Eisenmann H 2016 Ontology-based design of space systems Lect. Notes in Comp. Science 9982 308-24

[8] Nozhenkova L, Isaeva O and Evsyukov A 2018 Tools of computer modeling of the space systems’ onboard equipment functioning SPIIRAS Proc. 1(56) 144-68

[9] Isaeva O and Nozhenkova L 2019 Spacecraft onboard equipment testing automation technology on the basis of simulation model IOP Conf. Ser.: Mat. Sci. Eng. 537 032067

[10] Nozhenkova L, Isaeva O and Vogorovskiy R 2016 Automation of spacecraft on-board equipment testing AER-Advances in Engineering Research 52 215-7