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THE INFORMATION AND ANALYTICAL SYSTEM OF INNOVATIVE TECHNOLOGY FOR CREATING A PROMISING LAUNCH VEHICLE WITH IMPROVED ENVIRONMENTAL CHARACTERISTICS

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Abstract. The article is devoted to the problem of ensuring the ecological safety of the operation of rocket and space complexes. Within the framework of the concept of the controlled descent of the spent first stages of the launch vehicle, a fundamentally new approach to the problem of ensuring the environmental safety of land fall areas is proposed. This approach ensures fire and explosion safety and a decrease in the size of the fall areas as well as the extraction of unused fuel residues in the tanks and pipings of the worked-off stage for performing maneuvers to descend into a given region.

The object of research is the processes, as well as information flows circulating in the analytical information systems of the fall areas, the cosmodrome and the design bureau to develop recommendations for innovative technology for creating launch vehicles with improved environmental characteristics.

The objective of research is to analyze the state of the problem of technogenic impact of liquid-fueled launch vehicles and preparation of initial data for the development of an upgraded information and analytical system.

The presented original concept consists in a combined method of reducing the anthropogenic impact of the separated parts of launch vehicles by installing an additional system. This system provides a controlled descent of the worked-off stages to a given aiming point, and optimizing the fall areas based on the criteria of resistance to the technogenic impact of space rocket launches through the development of information and analytical system. A methodology has been developed for the selection of these sites, based on the creation of an information and analytical system for the area of the fall, which will become an element of the existing system of environmental monitoring of the Baikonur cosmodrome.

Key words: information and analytical system, database, launch vehicle, software package.

1. Introduction

The development of modern space vehicles, including advanced launch vehicles with liquid-propellant rocket engines (LPRE), in accordance with the accepted recommendations of such organizations as the UN technical Subcommittee on the peaceful uses of outer space (COPUOS), the inter-Agency space debris coordination Committee (IADC) [1] should be accompanied by a radical change in approaches to the process of creating and operating launch vehicles.

Currently, trends in reducing the man-made impact on the environment of launch vehicles with main liquid rocket engines (LPRE) to prevent explosions in the orbits of separating parts (SP) of launch vehicles are given in Support to the IADC Space Debris Mitigation Guidelines [2], and domestic works [3, 4].

However, there is a great example of a comprehensive solution to the problem. This refers to the SpaceX project, when the first stage of the launch vehicle after performing a maneuver in the atmosphere lands strictly in the designated place on the Earth's surface or in the ocean. In addition to SpaceX, a number of innovative projects (Blue Origin, Sierra Nevada Corporation, etc.) are

being built in the United States using a similar model [5, 6]). In [7], the possible flight patterns of the separating part of the first stage equipped with a rocket-dynamic rescue system are analyzed using the example of a medium-class oxygen-kerosene two-stage launch vehicle, which is similar in its energy and mass characteristics to the Falcon-9 launch vehicle (LV), compiled according to the results of ballistic design.

In turn, AIS is considered as an analytical information system for theoretical and experimental research and information support for bench tests of an Autonomous onboard descent system (AODS).

Main tasks in the development of AODS for the first stage:

- theoretical and experimental studies of evaporation processes in various schemes of heat supply to tanks;
- simulation of various descent schemes of SP 1, including the use of aerodynamic braking by the SP 1 body, etc.
- selection of AODS design parameters that increase not only environmental safety (ES) in the fall areas, but also increase other tactical and technical characteristics of the LV (payload mass, expansion of inclination ranges, reduction of the cost of launching the LV) , etc.

For the purposes of this research, the information and analytical system (IAS) is considered as a system that provides a procedure for analyzing and making recommendations on innovative technology for creating advanced launch vehicles with improved environmental characteristics.

The main factors of the technogenic impact of launches of LV with sustainer LPRE on the ecosystem of the allotted territories of Kazakhstan are reflected in a number of works [9, 10]. The development of promising launch vehicles with sustainer liquid jet engines, in accordance with the accepted recommendations [2, 8], provides for a significant reduction in the technogenic impact of the LV operation on the environment, including:

– preventing the clogging of near-earth space by upper WS with cruising LPRE, which are large-sized explosive space debris;

– a dramatic reduction in the number and areas of FA on the Earth's surface for the separating parts of the launch vehicle, which are fire hazardous and toxic objects, leading to chemical contamination of soil and soils with residues of liquid toxic PC such as: asymmetric dimethylhydrazine, nitric acid, kerosene

2 Analysis of existing information and analytical systems of the Baikonur complex

The IAS of the cosmodrome environmental monitoring system (CEMS) is designed for collecting, processing, analyzing, and summarizing environmental information when solving a set of tasks of scientific and technical support for environmental monitoring in terms of providing them with structured information in the decision-making system. It serves as the basis for industrial environmental monitoring, which is carried out within the framework of the departmental environmental monitoring system of the Baikonur cosmodrome (CEMS), linked to the Unified state system for monitoring the environment and natural resources of the Republic of Kazakhstan. It should be noted that State environmental monitoring is carried out by specially authorized state bodies of the Republic of Kazakhstan, in accordance with the Environmental code of the Republic of Kazakhstan. State environmental monitoring on the territory of the Baikonur complex is carried out in agreement with the authorized bodies of the Russian Side in accordance with the ownership of the objects.

Currently, the applied aspects of the IAS of the environmental monitoring system of the Baikonur complex are quite well developed. They are reflected in a number of main works on the functioning of the monitoring system, during the regular operation of rocket and space complexes and support facilities of the cosmodrome, as well as in possible emergency situations [9, 12].

The ideology of development of ecological safety of operation of space vehicles, as determined by the sponsors, is to develop recommendations for improving space-rocket equipment and technologies with improved environmental performance based on in-depth and comprehensive analysis of the environmental effects of space activities.

Based on the conducted research, it can be concluded that the existing IAS of the Baikonur complex do not fully reflect the issues of developing recommendations for improving and developing innovative technology for creating launch vehicles with improved environmental characteristics and require modernization.

The concept is based on three important postulates that take into account the features of land-based spaceports, as well as the requirements of the indigenous population to ensure quality living conditions.

Postulate 1. The life cycle of the WS should not end, as it is currently implemented in the logic of operation of almost all Russian launch vehicles launched from the Baikonur cosmodrome - by achieving the specified motion parameters, shutting down the sustainer LPRE. The operating stage of the WS, similar to the spacecraft, should still be implemeneted, which provides for its transfer to the disposal orbit after the end of the active operation period. At this stage, the WS must ensure that the technogenic impact on the environment in the area of its intended fall is minimized.

Postulate 2. At the present stage of the study, it is not expected to return the WS to the cosmodrome with its soft landing and subsequent reuse, similar to the first WS of the Falcon-9 launch vehicle.

Postulate 3. Perfect fall WS with practically dry fuel tanks and fuel lines with minimum deviation from the projected aiming point WS in the R-neighborhood from the optimum energy point of incidence of the WS.

IAS of the Baikonur cosmodrome is the basis for environmental monitoring of space activities on the territory of the Republic of Kazakhstan. The innovative nature of the creation of rocket units consists in a comprehensive solution to the problem: the development of rocket units based on gasification, the development of AODS, the evaluation of the results using the IASlv.

The interaction between IAScd and IASlv, like any information exchange between complex technical systems, is iterative in nature, which can be divided into several stages and levels, both as each IAS is ready and the current tasks solved by each IAS.

1) At the current level, the primary task is to create an IASlv and form a database for each FA of the most acceptable points of WS fall from the condition $\min \{C_i^{\text{v}}[\vec{R}_i(x_i, y_i)]\}$.

2) The information obtained is necessary for conducting research within the framework of IASlv, IASESLV for the following purposes:

a) synthesis of various control programs for the LV movement on the active section of the launch trajectory without taking into account restrictions on the areas of the WS fall (calculation $\vec{R}_{fra}(x, y)$);

б) distance estimation $\Delta\vec{R}$between $\vec{R}_{\text{fra}}(x, y)$ and recommended points of falling assets obtained in IASfa of conditions $\min\{C_i^{\text{v}}[\vec{R}_i(x_i, y_i)]\}$;

в) development of proposals for changing the design parameters of the WS for the implementation of maneuvers on the descent path.

Implementation of the presented concept of enhancing the ecological safety of launch vehicles with sustainer LPRE will reduce the environmental load on the environment in the FA of the Baikonur cosmodrome due to a dramatic reduction in the FA area (controlled descent of the WS), a significant reduction in the likelihood of vegetation fires (due to the almost complete extraction of liquid fuel residues), selection of the safest (from an ecological point of view) points of the fall of the environment in the territory of the designated FA.

3 Development of the initial data structure of the modernized IAS-M

The formation of the structure of the initial data is based on the ontology of information interaction of the IAS of various levels developed within the framework of the project (Figure 1).

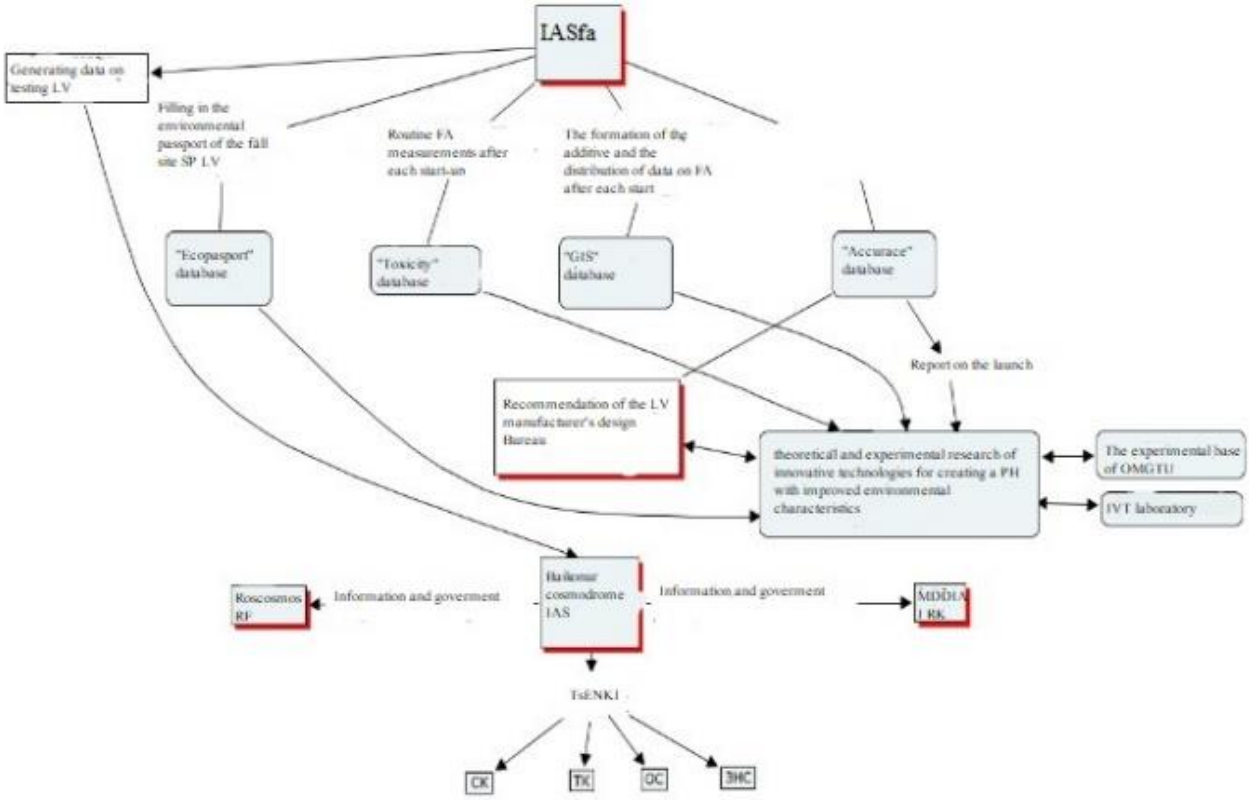

Figure 1 - IAS information interaction ontology

3.1 Development of the IAS-M functional structureThe functional structure of the IAS-M includes:

IASkd, - the existing IAS of the cosmodrome

IASfa- additionally created IAS of the area of the WS fall

IASlv - the existing IAS for the development of LV

IAS_{lv}^{es}- additionally created IAS for the formation of recommendations for the creation of a launch vehicle with improved environmental characteristics.

IASlv is designed to generate data when developing promising launch vehicles in the area of WS landing. Functionally, IASlv solves the following tasks:

а) according to the data received about the upcoming launch of the LV from the IASlv (the initial point of aiming the fall of the WS in the selected RP$\vec{R}_{pr}^{int}(x_i, y_i)$, optimal aiming point $\vec{R}_{fra}(x, y)$, at which the mass of the payload injected into a given orbit is maximum, the partition of the FA area into N sections with areas Si (i = 1, …N), so that $\sum_{i=1}^{N} S_i = S_\Sigma$;

б) in the selected N areas, N possible predicted coordinates of the points of WS fall are selected;

в) distances are estimated $\Delta\vec{R}_i = \vec{R}_{fra}(x, y) - \vec{R}_{pr}(x_i, y_i)$ to assess the possibility of the WS maneuver by shifting the point of WS fall by these values and are transmitted to the IASlv;

г) based on the passport of this RP is calculated for each predicted point of incidence $\vec{R}_i(x_i, y_i)$ environmental damage $E_i[\vec{R}_i(x_i, y_i)]$ from falling into this i-th section and, accordingly, the cost of restoration work $C_i^{\text{v}}[\vec{R}_i(x_i, y_i)]$;

г) the obtained information is transmitted to the IASrn for calculating the programs for controlling the movement of the launch vehicle in the active section of the injection trajectory and programs for controlling the movement of the WS in the section of descent to the selected point, which is determined from the analysis of the data array $\{C_i^{\text{v}}[\vec{R}_i(x_i, y_i)]\}$, оцScores of the ballistic capabilities of the AODS for maneuvering to change the coordinates of the point of incidence by $\Delta\vec{R}_i = \vec{R}_{fra}(x, y) - \vec{R}_{\text{прр}}(x_i, y_i)$.

As follows from the given Figure 2, it is possible to ensure the fall of the WS into areas with significantly different landscape conditions. In this case, it is assumed that an ABS is installed on the WS, which provides control of the OWSS movement on the descent trajectory. As a result of this control, the accuracy of the WS fall is similar to the accuracy of the SP1LV "Falcon-9" landing when landing on a cosmodrome or a floating barge.

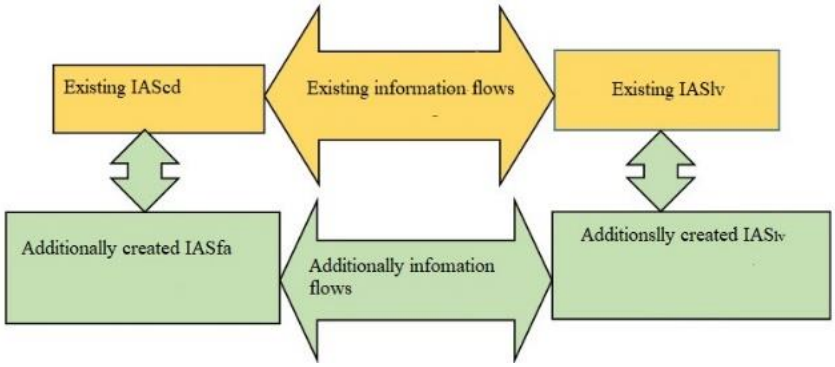

Figure 2 - General schematic diagram of information flows between IAScd, IASfa, IASlv, IAS_{lv}^{es}

In addition to the information received from the IASfa, which is necessary to improve the environmental safety of the LV, the IASfa is carrying out work.

3.2 Architecture of the IAS-M software package

The purpose of the software package is to ensure the management of the IAS, focused on achieving the goals of the project: researching an innovative technology for creating a launch vehicle with improved environmental characteristics.

The architecture of the software package (Figure 3) supports working with a distributed database. The system is divided into several subsystems ("nodes"), each "node" has its own database (DB). Synchronization of "nodes" with the central database is ensured through replications, which allows the use of the DBMS in conditions of insufficient bandwidth of communication channels.

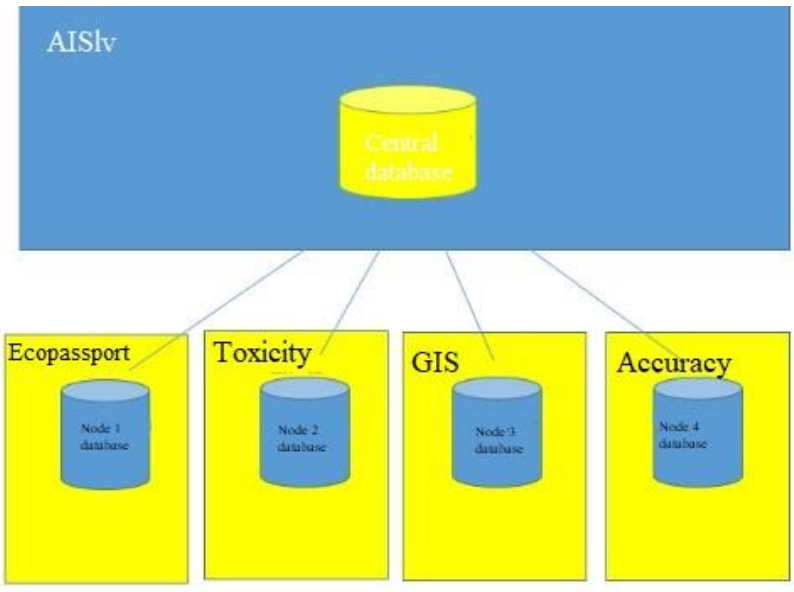

Figure 3 - Architecture of the software package

3.3 Initial data for IAS-M development

1) "Ecopassport»:

The subsystem concentrates the initial data containing data on the WS FA, which is necessary to ensure the functioning of the IAS-M during the regular testing and operation of the LV and includes:

- General information about the company responsible for the operation of the fall area;
- General information about the area where the SP LV falls and adjacent territories;
- Characteristics of natural and climatic conditions on the territory of the fall areas;
- Information about anthropogenic sources of pollution in FA and adjacent territories. Characteristics of the background ecological state of the NE;
- Characteristics of sources of FA pollution in rocket and space activities;
- Stability of soils;
- Impact of the SPLV in FA and adjacent territories;
- Levels of pollution of objects of the natural environment on the territory of FA and adjacent territories of RFC and their toxic derivatives: atmospheric air, biotic objects and levels of their pollution. Assessment of the environmental situation in FA and adjacent territories;
- Information about the amount of payments for pollution of the NE of FA, environmental protection measures
- Regulatory and reference data.

2) «Toxicity».

The subsystem concentrates the initial data containing data on the hygienic normalization of RFC and products of their chemical transformation in objects:

- Scale of contamination of FA RFC and products of their transformations;
- Characteristics of physical and chemical properties (PCP) and biological effects of liquid rocket propellants and their transformation products;
- Maximum permissible concentrations of rocket fuel components and some products of their chemical transformation in environmental objects;
- Results of in-house determination of rocket fuel components and products of their chemical transformation in environmental objects for each launch of the LV;
- Characteristics of physical and chemical properties and biological effects of liquid rocket fuels and their transformation products;
- Methods and technologies for detoxification of soils contaminated with toxic RFC;
- The initial concentration of RFC in the experimental sites and the results of quantitative chemical analysis;
- Results of identification of RFC and products of their transformation in soil samples before and after detoxification using the method of chromatography-mass spectrometry;
- Hygienic studies of FA and areas of influence;
- Regulatory and reference data.

3) «GIS».

The subsystem concentrates the source data containing GIS data for the WS FA:

- Attribute data on economic activity in a certain area of impact of separating parts of launch vehicles and in adjacent territories;
- Road network and terrain conditions;
- Power grid of the locality in FA;
- Cartographic materials: placing households in FA maps and FA maps FA soil, etc.
- Records of data on the number and coordinates of the fall of the WS in FA;
- SR (launch date, type of LV, SC, total launch mass of the LV);
- SR withdrawal routes on the territory of Kazakhstan;
- Regulatory and reference data.

4) «Accuracy».

В подсистеме концентрируются исходные данные, containing design parameters for ballistic descent WS results WS landing in FA for the evaluation of decisions made according to the requirements of the guaranteed drop at the given coordinates of the target point:

- Calculated data of the WS ballistic descent;
- Meteorological data for the launch day of the SR;
- Telemetry and external trajectory measurements on the active part of the trajectory (APT) of the first stage of the SR;
- Possible scenarios for the development of the environmental situation in the SRV areas, depending on the deviation from the specified coordinates of the aiming points;
- Regulatory and reference data.

5) « Modeling».

The subsystem concentrates the standard mathematical apparatus necessary for making recommendations for improving the LV.

4 Conclusion

1. The analysis of existing IAS is carried out. An ontology of IAS information interaction has been developed: IAScd, IASfa, IASlv, IAS_{lv}^{es} to assess the technogenic impact of the launch of the LV on the selected fall area, integrated into the General IAS of the Baikonur cosmodrome.
2. The functional structure and architecture of the software package were developed, and the initial data for the development of IAS-m were prepared.

5 Acknowledgements

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