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INFORMATION AND FORECASTING SYSTEM FOR DETERMINING THE LAUNCH AND IMPACT AREAS OF ULTRALIGHT LAUNCH VEHICLES, TAKING INTO ACCOUNT THE REQUIREMENTS OF ENVIRONMENTAL SAFETY

[1]YERMOLDINA G.T., [2]TRUSHLYAKOV V.I., [3]ALIPBAYEV K.A., [4]UTEGENOVA A.U.

[1]Institute of Information and Computational Technologies, Kazakhstan
[2]Omsk State Technical University, Russia
[3]Almaty University of Energy and Communications, Kazakhstan
[4] Institute of Information and Computational Technologies, Kazakhstan
e-mail: [1]gulerm@mail.ru, [2]vatrushlyakov@yandex.ru, [3]k.alipbayev@aues.kz, [4]utegenova77@mail.ru

ABSTRACT

The article reviews the state of development of launch vehicles (LV) intended for launching small spacecraft (SS), namely ultra-light LV (UL LV). The authors proposed the concept of information support for the operation of the UL LV, taking into account the requirements of environmental safety, based on the modernization of the rocket and the effective organization of environmental monitoring. This a fundamentally new concept that involves the introduction of technology for the controlled descent of a rocket unit and an ecological, economic, and technical assessment of the effectiveness of its operation.

Keywords: *Ultralight Launch Vehicle, Information And Forecast System, Environmental Safety, Controlled Descent, Impact Area, Spent Stage*

1. INTRODUCTION

The presence of own spaceport determines a number of political, economic, scientific and technical reasons, including considerations of a military-political nature, rocket and space ambitions, the scale of its own space program, the need for its own carriers, financial and economic opportunities, general scientific and technical potential; and sets the vector for its further development and increasing the services provided.

2. PROSPECTS FOR THE DEVELOPMENT OF ULTRALIGHT LAUNCH VEHICLES

Analysis of promising technologies and trends in the development of rocketry shows an increase in business and military interest in the creation of the UL LV. The expected increase in launches of femto-, pico-, nano-, micro-, mini- and small satellites for solving national economic, scientific and defense tasks also indicates the active development of the launch services market [1-4]. According to experts, the volume of the SS market in 2018–2026 could amount to about $ 30.1 billion

The situation in the field of enhancing space exploration and the development of launch vehicles is also characterized by many headlines in the media and popular thematic online sites [5-11]. It is not surprising that now there is an unprecedented "boom" of alternative projects of the UL LV and mini-cosmodromes for their launch.

Analysis of the development trends of the UL LV shows two evolutionary approaches:

– modernization of existing space rockets (SR) (such as the families "Pegasus", "Taurus", "Minotaur" (USA), CZ, KT-1 (China), PSLV (India), "Cyclone" (Ukraine);

– development and design of new highly efficient SR (such as Falcon-1e (USA), Vega (EKA), Epsilon (Japan), CZ-5-SSLV, - L (China), and others).

Creation of ultralight LV, designed to launch cargo up to 300 kg into low-earth orbit, imply flight tests in the coming years [1].

A number of companies are currently involved in the development of the UL LV: Firefly Space Systems, VirginGalactic, Interorbital Systems, Orbital Sciences Corporation, RocketLab, STC Complex-MIT, LLC Lin Industrial, PLD Space, Skyrora Limited and many others. In addition, market trends for private companies are already gaining momentum, as evidenced by a wide clientele, declared agreements and the growing demand for SS launch services [5-21].

Such launch vehicles are subject to requirements for reliability, simplicity of launch preparation, launch efficiency, low launch cost, high launch frequency, low risks and costs, the possibility of experimental testing of promising technological solutions that can be used on launch vehicles of heavier classes, minimization of the environmental impact on the environment.

The UL LV developments proposed today imply a low launch cost, high launch efficiency, low risks and costs, the ability to provide individual, independent of other payloads, launching into specified orbits with minimal restrictions on launch windows, payback and profitability. In addition, the development of the UL LV will make it possible to conduct experimental testing of promising technological solutions, including the use of 3D printing in the manufacture of structural elements, a salvage block of the first stage, reusable use of launch vehicles, the use of new light alloys and composite materials, combustion of separating elements of the launch vehicle in the process of launching (interstage compartments, nose fairings), preparation and launch of the launch vehicle from a mobile launch platform in a semi-automatic mode, the introduction of advanced technologies for propulsion engines, control systems that can be used on launch vehicles of heavier classes, etc.

Among other things, the advantage of the UL LV is the possibility of more frequent launches that are not tied to launches of heavy LV to solve the problem of replenishing satellite constellations. For example, already now, to replenish the composition of the global broadband communication system OneWeb, it is planned to use the ultra-light launch vehicle Launcher One (Virgin Galactic, USA), and Planet (USA) plans to replace the failed Flock satellites (3U cubesat form factor) of the Earth remote sensing system using ultralight LV Electron (Rocket Labs, USA) [20], etc.

The analysis of well-known foreign research on the creation of the UL LV shows that currently certain results have been achieved in the creation of the UL LV [14-24]. Among them:

- LV SS-520 № 4 (Japanese solid-propellant three-stage rocket) [18];
- LV Electron of the New Zealand company Rocket Lab [20];
- Ultralight LV Alpha, start-up Firefly Space Systems (US) (2014) [19];
- The two-stage ultralight launch vehicle Vector focused on the commercial micro- and nano-satellites market by Vector Space Systems [21];
- The ultralight launch vehicle with a reusable first stage Arion 2 (Miura 5) of the Spanish company PLD Space, designed to launch 150 kg of payload into LEO (with a change in the design of the rocket and an increase in payload up to 300 kg) [16];
- The Skylark L LV of Skyrora Limited has passed a full-scale test, its flight is scheduled for the middle of next year [8];
- a solid-propellant LV of the "Start" family, created on the basis of the “Topol” intercontinental ballistic missile, capable of launching a payload of 490-1000 kg into orbits with an altitude of 200-1000 km [9-10];
- Russian launch vehicle "Akvilon", the estimated carrying capacity of which is up to 450 kg [9];
- the project of a two-stage launch vehicle for space purposes UL "Aldan" with a payload of up to 100 kg on environmentally friendly fuel components. The project received a positive assessment from experts from the Space Technologies and Telecommunications Cluster of the Skolkovo Foundation [11];
- modernization of the existing rocket meteorological complex MH-300 [23, 25] and many others.

3. MOBILE LAUNCH COMPLEXES

Today, urgent launches of small satellites are almost impossible to carry out due to the lack of a rocket. Production cycles are scheduled for years ahead, so unscheduled high-demand launches are difficult for commercial purposes and attractive for military tasks [23]. The criticality of disruption of the launch schedule is fraught with financial losses and delayed development of technological solutions. According to experts, urgent launches are in demand for the fastest possible shooting of the desired region, even in the presence of reliable constellations of long-lived satellites, all of them may be either unavailable or insufficiently effective. The imposed limitations of the modern technological process of launching the LV also include the priority of the interests of the owner of the main rather than associated cargo, which are mostly small spacecraft.. In this case, the attractiveness of the development of all kinds of projects of the UL LV increases many times over..

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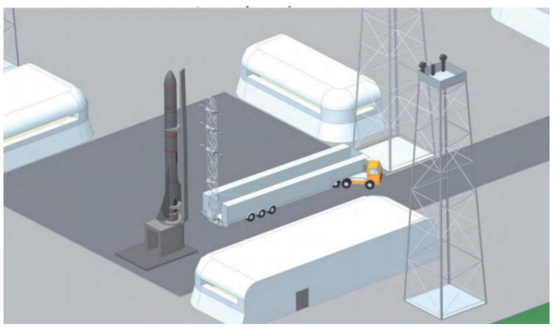
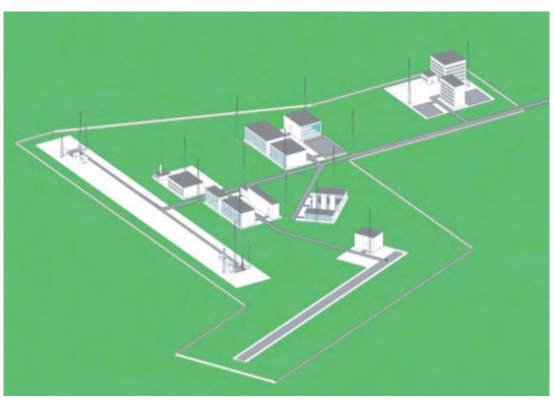
For urgent unscheduled launches, it is advisable not to use the main cosmodromes - if it is a (pre-) war period, then they will probably either be busy replenishing the national constellation of "large" satellites (for example, geostationary communication satellites or navigation satellites), or removed from building. In peacetime, they are engaged in planned commercial and scientific activities, and it is unacceptable to interrupt it for minor reasons..

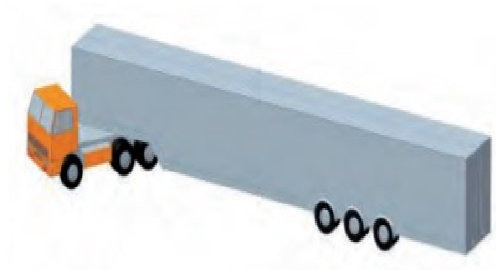
For a launch vehicle of this class, it is possible to create a mobile launch complex and allocate zones of missile block fall: either a stationary launch complex using an installer, or from a mobile ground launch complex (ground cargo transport with a launch device, a mobile filling station and a flight control complex, figure 1-3) [9, 24-27].



a) stationary launch complex using the installer



b) mobile ground launch complex (cargo ground transport with a launch device, a mobile refueling station and a flight control complex)
Figure 1 – mobile launch complex [9]



a) Transportation

b) mobile refueling complex

c) Launch of a mobile platform with the involvement of auxiliary starting means
Figure 2 - Launching means of UL LV [9]

Figure 3 - Tests of the Skylark L LV by Skyrora Limited [8]

The advantage of the UL LV operation is the ability to launch from any location that meets safety requirements and is suitable in terms of the parameters of the target orbit. Therefore, in accordance with the Agreement on the Use of Natural Resources, mobile launch complexes for launches of the UL LV should be provided with environmental safety standards, environmental control and monitoring services, measures to clean up the impact areas (IA) from the used parts of the LV, regulatory and legal documentation in terms of exceeding the discharge limits , environmental and economic assessment of damage and risks, and others.

4. STATEMENT OF THE PROBLEM

The choice of the location for the localization of the mobile cosmodrome is due to taking into account such factors as the presence of exclusion zones (areas of unpopulated or sparsely populated areas) for the fall of detachable parts of missiles in normal and emergency situations, as well as a well-developed network of transport and energy highways. The geographical location of the launch site is also important. For example, depending on the latitude of the launch site, the addition to the characteristic velocity of the rocket changes due to the daily rotation of the Earth: an additional linear velocity (at the equator 465 m / s, at the latitude of Baikonur - 316 m / s) at a given power of the LV makes it possible to put into orbit in the eastward direction is a payload of greater mass. Weather conditions in the area of the cosmodrome are also important - a large number of cloudless and, if possible, windless days per year make it possible to more effectively use the optical means of tracking the LV flight.

An example of a ground-based mobile launch is the “Start-1” space rocket complex, in which a solid-propellant LV is launched from a transport and launch container placed on a high-performance wheeled chassis.

Each launch complex is equipped with systems for refueling the carrier with propellant components, a missile service tower on the launching device, prelaunch equipment and a launch / flight control center. The compact placement of the cosmodrome complexes and their grouping by carrier classes are of great importance for expanding the ranges of the sectors of the launch azimuths from each launch complex, for the centralized use of equipment and facilities of the cosmodrome.

Based on the analysis of global trends in the development of the UL LV, it is possible to identify the main current research areas:

- predictive assessments of the environmental load in the areas of UL LV operation and

- design and search studies of our own independent system, which ensures the controlled descent of spent missile units into a given territorial framework.

The concept of ensuring environmental safety of the UL LV operation should provide for an inventory of the territories allocated for launch and impact areas to identify areas that are least sensitive to man-made impacts when the spent stage falls (stage 1) and develop a method for forming an array of coordinates for possible locations of mobile ground-based spaceports and targeting spent stages based on the database obtained at stage 1 (stage 2).

5. PROPOSED CONCEPT

The authors propose a fundamentally new concept that involves the introduction of technology for the controlled descent of a rocket unit and an ecological, economic and technical assessment of the effectiveness of its operation. The Kazakh and Russian sides are interested in the creation of a LV that would have the least environmental impact on the impact areas of the separating parts of the LV located on the territory of the Republic of Kazakhstan and neighboring states.

Taking into account the long-term Russian experience in the development and application of more than 50 modifications of research meteorological rockets, the concept of ensuring the ecological safety of the UL LV operation at the last stages of its life cycle is proposed [28]. The proposed concept is based on the principles of effective modernization of the LV and the organization of appropriate information support at the launch and landing stage, taking into account the requirements of environmental safety. Accordingly, it provides for the scientific and methodological development of its main provisions, including:

– models of an information and prognostic system for determining the areas of launch and impact of the separating parts of the UL LV based on a system analysis, which includes the analysis of launch targets, the energy capabilities of the UL LV, the coordinates of the areas of impact, taking into account the minimization of the environmental impact on the environment;

– research in ensuring the creation of on-board systems that implement a controlled descent

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of the spent first stage of the UL LV into the recommended impact area for various directions of development (modernization of the existing UL LV based on solid-fuel accelerators of the first stage [27-28], promising developments of the UL LV based on liquid engines [29 -30] and

- development of the technology of combustion of the interstage transitional compartment and the flaps of the head fairing.

The implementation of the concept based on the modernization of the UL LV will allow:

– consider the UL LV as a promising element for training and retraining of personnel for the Kazakh rocket and space industry being created;

– reduce the environmental load on the natural environment, including in areas of fall;

– create operational reserves of launch and landing points and monitor these points.

Thus, if we use the main criterion - the indicator of the ecological efficiency of the rocket and space system based on the UL LV, take into account the costs and financial losses for the restoration of the ecological situation in the impact areas, then the implementation of the project seems appropriate [31-32]. In addition, compliance with the principles of environmental safety for the development of the space infrastructure of the civil and defense complex of the Republic of Kazakhstan in the implementation of rocket and space activities [32in particular during operation and launches of small spacecraft for various purposes is an urgent task.

The results of comprehensive studies carried out within the framework of the AR05131162 project "Theoretical and experimental studies of an innovative technology for creating a launch vehicle with improved ecological characteristics on the example of promising launch vehicles launched from the Baikonur cosmodrome" together with leading Russian scientists will serve as the basis for the development of promising launch vehicles and will allow to work out the design parameters of the launch vehicle for controlled descent of spent stages [25, 27-30, 33-42].

6. INFORMATION AND PROGNOSTIC SYSTEM FOR DETERMINING THE LAUNCH AND OPERATION AREAS OF ULTRALIGHT MISSILES

As a solution, it is proposed to develop a model of the information and forecast system of the Baikonur cosmodrome to determine the launch and impact areas of the parts of ultra-light launch vehicles that are separated in flight (spent stage boosters, interstage transition compartments, nose fairing flaps) and a set of technologies that ensure the requirements for the environmental safety of launches ultralight launch vehicles.

The main tasks facing developers include:

a) development of a model of an information and forecasting system (IFS),

b) development of effective technologies that ensure controlled descent of spent stages of specific UL LV to the recommended impact areas based on the creation of onboard UL LV systems.

The proposed tools for performing the above tasks were not found in the process of information search through open sources. The need to create the proposed rocket and space complex, which includes the UL LV, technical and launch complexes for launch preparation, ISS, crash areas, is due to the rapidly growing demand for this type of service in foreign countries. The solution of the above tasks is planned to be achieved on the basis of:

a) synthesis of elements of the created ISS, which differs from the existing analytical information system of the Baikonur cosmodrome;

б) development of scientific and methodological recommendations for the on-board systems of the UL LV based on the use of modern scientific and technical solutions.

Figure 4 shows the structure of the information and forecasting system.

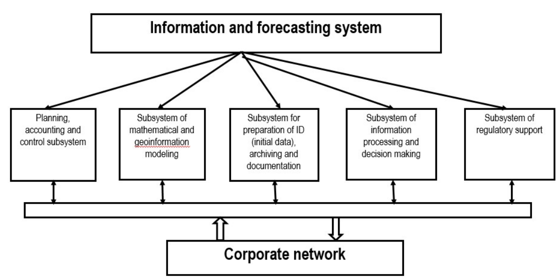

Figure 4 - Information flows and structure of the information forecasting system

The basic concept for the development of the information and prognostic system for determining the launch and impact areas of the UL LV includes the basic provisions for reducing the technogenic impact of rocket and space activities in the impact areas of the Baikonur cosmodrome, the development of methods for selecting launch and impact areas, automation of processes for the operational assessment of the technogenic impact from the moment of UL LV launch till the elimination of the consequences of the launch in the

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impact areas. This is necessary for the preparation and analysis of statistical data. All entered data will be of a reference nature, for visualizing potentially safe launch points on a geographic map, with delimiting access to data for various user groups and processes.

The proposed concept of reducing the technogenic impact of the spent stages of the UL LV on the environment includes the following basic scientific and methodological provisions:

a) development of scientific and methodological recommendations for the selection of launch and impact areas for specific LV of the UL on the territory of the Baikonur cosmodrome based on the ISS being created, which includes:

- selection of possible areas of launch and fall from the condition of minimizing environmental damage to the environment based on the developed criteria used in the zoning of the study area and the development of a classification system for operational-territorial units,

- reduction of anthropogenic impact in the selected impact areas by minimizing the spread of points of fall of the separating parts, minimizing the probability of fires and explosions.

б) development of scientific and methodological recommendations on a set of technologies that ensure the requirements for the environmental safety of launches of ultra-light launch vehicles, including:

- minimization of the territory size of the impact areas of the separating parts, for example, burning in the passive flight section of the wings of the head fairings, interstage compartments, picking up the spent stage by a helicopter,

- reduction of anthropogenic impact in the impact areas by minimizing the likelihood of fire and explosion hazard by gasification of non-worked off fuel residues in the stages of the UL LV, etc.

When developing an IFS, scientific issues are the determination of the performance of calculations and the automation of the classification process of operational-territorial units. The accepted hypothesis for its solution is the use of optimal methods and the development of data processing algorithms that determine environmental sustainability, taking into account the developed criteria on the basis of a unified database of environmental indicators. When developing the UL LV, scientific issues are the extraction of energy resources from non-spent residues of liquid fuel. The accepted hypothesis for the solution is to test its feasibility by transferring from the liquid phase to the gas phase. If a solid propellant engine is used, then the scientific question is the search for a method of descent control, the accepted hypothesis is the installation of a gas installation, possibly using hydrogen peroxide, etc.

To achieve these goals, the IFS software includes software complexes and decision-making algorithms developed on the basis of control theory methods, game and decision theory, experiment planning theory, regression analysis of time series, as well as methods of mathematical modeling using numerical methods for solving complete equations Navier-Stokes and energy equations. These methods will ensure the establishment of a regression regularity in assessing the factors of the technogenic impact of the UL LV with a liquid-propellant rocket engine (LPRE) or solid-propellant rocket engine (SPRE) on the environment, depending on the technical characteristics of the UL LV, primarily in the area of fall (explosion height, deviations of drop points , fires, spills of fuel residues, the degree of structural destruction, etc.) depending on the amount of fuel residues in the tanks of the spent stages of the launch vehicle. The next stage in the development of the IFS is the distribution of the obtained developments to the LV stages, which, after completing their mission, remain in the launch orbits.

Development of technologies, schemes and design solutions to reduce the technogenic impact on the environment of launches of the UL LV based on the recommendations of the IFS.

The technologies proposed in the project depend on the type of propulsion systems: LPRE or SPRE. If it is a LPRE (for example, promising Russian launch vehicles Aldan, Akvilon, etc.), then heat is considered to be supplied to the fuel tanks after the main LPRE is turned off and the fuel and oxidizer fuel lines are purged from the main LPRE valves into the corresponding tanks. After turning off the rocket engine, liquid fuel residues remain in the tanks, for example, oxygen in the oxidizer tank, kerosene, liquefied natural gas in the fuel tank. For the evaporation of liquid fuel residues, it is proposed to supply a heat carrier in the form of hydrogen peroxide decomposition products. This technology is used for the promotion of turbopump units on the launch vehicle of the Soyuz type. Gasification products from the stage fuel tanks are used to control the descent of the spent stage to the recommended impact area.

In the event that a spent stage has a SPRE (for example, an upgraded MR-300 meteorological rocket), then a controlled descent is possible using an autonomous gas-cylinder propulsion system, which is installed on the spent stage (analogous to the spent accelerator of the first stage Falcon-9 SpaceX).

7. CONCLUSION

In both versions (SPRE, LPRE), it is possible to pick up the spent accelerators of the first stages of the UL LV in flight using a helicopter, which will require the installation of parachute systems.

It is proposed to study the possibility of burning the spent separated structural elements of the UL LV, such as the interstage compartments, flaps of the nose fairings. These structural elements should be designed and manufactured from polymer composite materials with special properties that ensure the performance of regular functions and the possibility of incineration after completing the mission.

The proposed technologies and design solutions are based on the elements of proven solutions; the combustion of structures separated from the launch vehicle in flight is essentially new.

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