The designing of launch vehicles with liquid propulsion engines ensuring fire, explosion and environmental safety requirements of worked-off stages

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\textbf{ABSTRACT}

The paper addresses the problem of the launch vehicles (LV) with main liquid propulsion engines launch technogenic impact in different environment areas.

Therefore, as the study subjects were chosen the worked-off stages (WS) with unused propellant residues in tanks, the cosmodrome ecological monitoring system, the worked-off stage design and construction solutions development system and the unified system with the “WS+the cosmodrome ecological monitoring system +design and construction solutions development system” feedback allowing to form the optimal ways of the WS design and construction parameters variations for its fire and explosion hazard management in different areas of the environment.

It is demonstrated that the fire hazard effects of propellant residues in WS tanks increase the ecosystem disorder level for the Vostochny cosmodrome impact area ecosystem.

Applying the system analysis, the proposals on the selection of technologies, schematic and WS design and construction solutions aimed to the fire and explosion safety improvement during the LV worked-off stages with the main liquid propulsion engines operation were formulated.

Among them are the following: firstly, the unused propellant residues in tanks convective gasification based on the hot gas (heat carrier) supply in WS tanks after main liquid propulsion engines cutoff is proposed as the basic technology; secondly, the obtained unused propellant residues in WS tanks gasification products (evaporated propellant residues + pressurizing agent + heat carrier) are used for WS stabilization and orientation while descending trajectory moving. The applying of the proposed technologies allows providing fire and explosion safety requirements of LV with main liquid propulsion engines practically.

\textbf{Introduction}

Currently, the parts separating in flight, in particular WS and unused liquid propellant residues components in tanks is one of the major problems related to LV with main liquid propulsion engines launches [1–6]. This problem therefore poses several resulting sub-problems considered in this paper:

a) the necessity of economic entities territories vast areas providing for the cosmodrome on a permanent or temporary basis connected with a number of political, social and economic issues solution;

b) the unused propellant residues in WS tanks leads to the high possibility of explosion while its prolonged remaining on orbits, moving on the descending trajectory atmospheric phase or upon the Earth surface in the impact area and consequently results in the high possibility of fire hazard that leads to the related problems in WS falling in the taiga regions;

c) the upper WS with unused propellant residues that remains in the insertion orbits are bulk explosive space debris creating potential risk for the functioning space systems.

The above issues lead to the necessity of carrying out of the high-volume set of studies and design and construction works implemented by the engineers of LV with main liquid propulsion engines aimed at technogenic impact reduction in different areas of the environment. This complex of works includes works on the developing management
algorithm for propellant expenditure in tanks, introducing separate propellant filling in tanks for each LV launch, works on propellant residues quantity in tanks reduction, conversion to the less toxic propellant components, the impact areas quantity and territories reducing, etc.

In Russia, the choosing design and construction parameters of LV stages including the advanced LV was carried out applying the condition of orbital payload maximum mass insertion into the specified orbit under the impact areas restrictions and propellant in WS tanks minimizing [7] unlike the design conception used in the USA, in particular in the SpaceX company [8].

Nowadays on the basis of the “Proton-M” LV stage improvement experience, the approach to the items producing process in which separate problems solving and required characteristics achievement initially were postponed at the stage of flight and development tests for making decisions after flight statistics collecting, is applied.

This approach is implemented for the “Angara” LV where the achievement of a number of characteristics is carried over to the flight and development tests stage and possibly to the subsequent stages [7].

In the present study the concepts content defining the traditional LV stage [1,3,4] and a worked-off one differ. Design and construction parameters of the traditional “dry” LV stage and “dry” WS being equal, the difference begins from the moment of the separation from the LV. These differences between WS and LV stage are defined by the following items:

– the moment and centering characteristics, as the unused propellant residues in tanks, feed lines, the pressurizing gas in tanks, the residual gas in spherical tanks etc. are part of the WS;

– the trajectory parameters and aerodynamic and inertia loads accordingly acting in the case of their functioning;

– the WS lifetime is determined by its location area after the separation from the LV.

Besides, the LV worked-off orbital stage that has just put the payload into orbit and the LV spent stage that remains on orbit for a long time should be distinguished.

Considering that there is an intensive launch program of advanced LV with main liquid propulsion engines of “Angara”, “Soyuz” families from the Vostochny and the Plesetsk cosmodromes, the fire and explosion safety issues become more relevant in comparison with the similar problems arising on the LV launches from the Baikonur cosmodrome. This difference results from the fact that the WS impact areas of the Baikonur cosmodrome are mostly situated in desert and steppe regions [9,10], while the WS impact areas on launches from the Vostochny cosmodrome are mostly situated in taiga forest regions with the high fire hazard [11,12]. In addition, there is a requirement of strengthening the tendency of international organizations to reduce the pollution by the LV worked-off stages of the near-Earth space environment protected areas [13].

In this regard, the fire and explosion safety problem solution during the LV with the main liquid propulsion engines operation is the relevant objective when the Vostochny cosmodrome is operated. There are practically no that kind of problems for the LV engineers and operators for the cosmodromes located on the World Ocean coast (the USA, EU, Japan, India, etc.) as the WS impact areas are located in the World Ocean. The problems on the fire and explosion safety requirements ensuring of the WS impact areas on the launches from the Vostochny cosmodrome are suggested to be solved on the basis of system approach [14], including the use of the required characteristics achieving transfer method to the flight and development tests stages [7].

1. The estimation of fire hazard in the WS impact areas under LV launches from Baikonur and Vostochny cosmodromes

It is important to note that the general fire hazard of the impact area consists of two components: meteorological fire hazard and fire hazard of vegetation cover inflammability in impact areas. With regard to meteorological fire hazard, it is defined by the temperature impact, air humidity conditions, a number of other meteorological factors, such as season, geographical position, etc. Currently the significant factual and methodic material on the estimation of meteorological fire hazard is accumulated, for example, the Nesterov criteria, etc. [15]. While the fire hazard of vegetation cover inflammability is defined by the material property that is by such factors as burning, inflammability [16].

As follows from the geographical position of the impact areas, generally they are not flammable as most of them are covered with sparse semi-desert vegetation. There are only separate flammable regions but they are small in area and located in the rivers and streams valleys. The period from the moment of snow cover melting till steady rainy autumn weather coming or snow cover forming is considered to be flammable. For the case in question it corresponds to the period from the late March – early April till the first decade of November [11,12].

It is worth mentioning that meteorological fire hazard of Vostochny cosmodrome impact areas is generally close to fire hazard of Baikonur cosmodrome impact areas, however, on burning, inflammability parameters they are significantly differ from the discussed above Baikonur cosmodrome impact areas fire hazard. For Baikonur cosmodrome impact areas it is mostly desert vegetation, while for Vostochny cosmodrome ones it is softwood forest. Burning, inflammability of coniferous vegetation is tremendously higher than of desert one [14].

Additionally, another factor increasing vegetation inflammability is the type of propellant components. If from Baikonur cosmodrome the LV were launched with unsymmetrical dimethylhydrazine, nitrogen tetroxide, oxygen, kerosene components, while from Vostochny cosmodrome oxygen, kerosene propellant components will be used [12]. According to the preliminary conducted estimations [12], one can assume that inflammation conditions of the same vegetation using oxygen, kerosene propellant components is higher than when using unsymmetrical dimethylhydrazine, nitrogen tetroxide propellant components.

2. The problem formulation on the complex approach implementation to the WS fire and explosion safety improvement problem during the LV with main liquid propulsion engines operation

Primarily, in order to select technological, schematic and design and construction solutions for LV, providing the given level of fire and explosion safety on the basis of system analysis methods it is proposed to examine conjunct system “WS+the cosmodrome ecological monitoring system+design and construction solutions development system”, including: the WS, the cosmodrome ecological monitoring system and the design solutions development system by the LV engineer.

While analyzing “WS+the cosmodrome ecological monitoring system+design and construction solutions development system” system functioning, the environment portioning into four regions is carried out where the WS can be belong - {R1}, {R2}, {R3}, {R4}.

Firstly, the region {R1} where the WS after payload separation is located. The period of WS location in this region can range from a few to hundreds of years, for example, orbits more than 800 km in height. The region {R1} is the volumetric region Vws of size and its value can be assumed that in

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