Development of proposals for the synthesis of polymer composite materials capable of combustion after the mission

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Abstract. One of the ways of solving the problem of reducing the man-made impact of rocket and space activities on the environment, based on the reduction of the impact areas of separating launch vehicle component (LVC) in the process of launching payloads into orbit are considered. Known particular solutions to this problem, for example, the return of spent LV stage accelerators to the point of launch, a multiple reduction in the impact areas of spent LV stage accelerators due to their controlled descent, however, there is open the question of how to deal with such LVC as payload fairings (PF) and aft-interstage (AIS) having significant areas of the impact areas. The possibility of burning LVC, such as PF and AIS, made of a composite material based on carbon fiber is considered. The thermal conditions of LVC during their movement on the descent path are investigated, the necessary amount of heat for heating the LVC to the ignition temperature is determined and various options of energy materials (EM) are considered. On the example of a typical PF, having a design of a polymer composite material (carbon fiber) with an aluminum honeycomb core (AHC), another structure is proposed, where a filler based on a mixture of polymer films such as ABS structure and energy material is used instead of AHC. The proposed design of the polymer composite material allows to provide the necessary operation parameters of the PF (strength, thermal protection, etc.) at the stage of preparation of the PF for a launch, LV ascent in the active section of the trajectory. And the possibility of burning after the mission with minimal energy costs allows to provide.

1. Introduction
When LV launching in the ascent trajectory to separate the spent LVC such as accelerator stages, PF and AIS (figure 1, 2, 3).
The fall of the separable components to the Earth’s surface is a source of economic, environmental and social problems arising in the implementation of rocket and space activities.

Specificity of the considered class of separable LVC such as payload fairing is that the velocity of their re-entry into the atmosphere at the altitude of 100 km are 1.0 - 1.5 km/s, which is several times less than re-entry velocity for exhausted stages of LV and spacecrafts when they descend from operational orbits (6 - 8 km/s), which burn almost completely when moving in the atmospheric section of the descent trajectory.

Due to the peculiarities of the dynamics of PF flight in the atmospheric phase of the descent trajectory, the heating of PF is significantly lower than when moving as part of the LV at the ascent trajectory [1]. This is leads to the fact that to ensure the combustion process of PF in the oxygen of the incoming air flow, an additional supply of heat is necessary, which would ensure the heating of PF to the ignition temperature and the subsequent combustion of the PF material in the presence of atmospheric oxygen. As an additional source of heat, it is proposed to consider pyrotechnic compositions (PC) placed in the PF structure. PC initiation is carried out at the entrance to the dense layers of the atmosphere.

As PC it is possible to use mixtures with powdered metal, one or more, for example, with powders of magnesium, aluminum, titanium or their alloys, as well as salts or oxides of metals: potassium chlorate, potassium perchlorate, copper oxide and others. The use of a particular PC composition, its quantity, depends on the necessary temperature increase required for the complete combustion of PF.
in the atmospheric phase of the descent trajectory. The PC location in a PF structure it is possible in two variants [2,3]:

- The location of the powdered mixture directly in the honeycomb three-layer structure of PF;
- The use of adhesives for PC bonding in the form of plates on the PF inner surface.

The proposed direction of reducing the impact areas of PF radically solves this problem. It is allows to choose the optimal LV pitch programs without taking into account the requirements to ensure the PF fall in specific allocated impact areas. It is allows to abandon the allocation of impact areas and work on the search, cutting and removal of PF to places of storage and disposal [4]. Ultimately, this results in a significant reduction in the cost of LV operating, reducing economic and social issues with the regions in which the impact areas are located.

2. Statement of the problem

The PF structure consist of a three-layer structure, in which the outer and inner bearing layers are made of a composite polymer material based on carbon fibres. Between these layers there is a filler made of aluminum alloys, which provides flexural rigidity and stability of the entire PF structure [5]. Thus, the combustion problem of the PF is solved to the ignition of carbon fibres, which upon combustion produce heat, sufficient for the subsequent combustion of the remaining part of the PF structure in the atmospheric phase of the descent trajectory.

Heating of the external PF structure layers is carried out by burning the most energy-generating material (EM) installed in the PF structure.

However, it is known that aluminum burns in air only in finely dispersed form [6], and when heated to 660°C it is in liquid form.

There are several schemes of heat supply depending on the EM used, namely:

a) Placement the pyrotechnic compositions in the AHC [1, 2];

b) Use of heat supply based on gas combustion of propane (or hydrogen) and oxygen;

c) Replacing the AHC with a solid-fuel EM, which provides the necessary strength and heating value [3].

3. The results of the conducted preliminary research

3.1. Placement the pyrotechnic compositions in the AHC

At the first stage of selection of all known pyrotechnic compositions were discarded having in its composition volatile, radioactive, alkaline and rare earth components. For the research was selected several different recipes of gasless compositions comprising:

- Powders mixtures of active metals with oxides of less active metals.
- Powders mixtures of two metals or metal with carbon, capable of burning with the produce of a large amount of heat without the formation of gaseous reaction products.

According to the results of the researches with the selected compositions, experiments with mechanically activated pyrotechnic composition B4C-4Ti, providing a gasless combustion regime, showed the maximum destruction of the PF structure element [7,8,9].
Figure 3. Results of experiments with mechanically activated pyrotechnic composition B4C-4Ti

A characteristic feature of the experiments is the complete burnout of the polymer component from the sample. Thin plates of the original graphite base keep easily separated from each other. In experiments with the location of the pyrotechnic composition in the honeycomb filler, the complete combustion of aluminum honeycombs is recorded and in their place, there are easily detachable combustion products of the initial condition in the form of layered cylinders.

3.2. Use of heat supply based on gas combustion of propane (or hydrogen) and oxygen

Providing the conditions of heating up to the ignition temperature is planned after their separation from LV during its movement on the descending part of the atmospheric phase with the amount of oxygen that is sufficient for the carbon fiber composite burning maintenance. It is assumed that combustion of carbon fiber composite begins when the ignition temperature (above 1000 K) is reached, after which the exothermic process with the release of a significant amount of heat is realized.

Previously, the PF structure is divided into N parts with corresponding masses $i = 1, 2, \ldots, N$, on which heating elements are installed which provide the heating the selected piece from the current temperature up to the carbon fiber ignition temperature.

The combustion module includes propane and oxygen tanks, burner nozzles, a gas supply system, an ignition system and protective heat shields.

Figure 4 shows the scheme of the combustible structure heating.

Figure 4. The scheme of the combustible structure heating: 1 - carbon fiber shell; 2 – heat shield against reverse heat flow; 3 - heat fluxes (- conductive, convective and radiation component, and convective heat loss, respectively; 4 - external oncoming airflow.
When using ANSYS FLUENT for 30 seconds of the combustion module operation at a total mass flow rate of the oxygen-propane mixture (4:1) 0.12 kg and with a calorific value of propane 46.3 MJ / kg, the outer surface of the wall on a spot with a diameter of ~ 0.24 m (by mass 0.5 kg) is heated to a combustion temperature. At the same time, the environmental conditions at an altitude of ~ 5000 m were simulated, with standard atmospheric parameters for a given height.

Further combustion process using heat from burning carbon fiber was not considered.

3.3. Experimental study of the evolution of the three-layer structure with AHC when heated to a temperature close to the temperature of carbon fiber ignition with the use of optical registration of the evolution of macrostructure

![General view of composite material: 1-carbon fiber plates, 2-honeycomb aluminum filler.](image)

Optical registration of macrostructure evolution under its linear heating under similar conditions (in air at 10 deg/min) is presented in figures 5, 6.

When heating of the carbon sample using device simultaneous thermal analysis consistently place the three main process:

(1) evaporation of the binder plasticizer, accompanied by a loss of 13% of the sample mass, begins at ~360°C;

(2) the exothermic decomposition of the resin, with a loss of 20% by weight and an effect of 2100 J/g, begins at temperatures above 450°C;

(3) oxidation of carbon contained in carbon filaments with a significant thermal effect of 23,500 J / g to form gas-phase products begins at temperatures above 700°C.
Figure 6. Evolution of the structure of a three-layer structure with AHC during heating

Changes in the macrostructure of carbon fiber are visually observed at a temperature above 600°C - on the surface there are signs of "fluidity" of the binder, and at 720°C there is an almost complete loss of the binder, the stratification of carbon fiber into individual elements with signs of burnout of carbon filaments. Note that the aluminum honeycomb core retains its stability up to 720°C. Starting from 770°C on the site of the composite material there are separate carbon filaments and swollen parts of the aluminum profile.

4. Discussion and proposal of alternative material instead of AHC

The conducted experiments on combustion (heating and bringing to the destruction of the sample of the three-layer structure of the PF) showed that the AHC is not a combustible element, since the combustion of aluminum is possible only in fine dispersed form.

As a basic technical solution for the PF combustion is considered a replacement in the material of PF structure (three-layer with sheathing of carbon fiber and AHC) AHC to another filler, providing similar strength, performance, technological characteristics, and emitting a sufficient amount of heat during combustion, for example, a polymer material based on ABS structure [10].

Taking into account the fact that the ABS material with the inclusion of EM is obviously inferior in strength characteristics to existing metal structures (for example, aluminum-magnesium alloys), it is proposed to replace the construction of the honeycomb filler with others having higher parameters of strength and stability.

Figure 7 shows alternative structures for the filler in a three-layer PF. The replacement of ASZ with trapezoidal corrugations, rod structure or similar variants, providing the specified parameters of strength and stability of the PF structure at all stages of the product life cycle, is considered.
5. Conclusions

- One of the ways of solving the problem of reducing the man-made impact of rocket and space activities on the environment, based on the reduction of the impact areas of separating LVC in the process of launching payloads into orbit are considered.
- The possibility of LVC burning, such as PF, made of composite material, based on carbon fiber during their movement in the atmospheric phase of the descent trajectory is shown.
- On the example of a typical PF, having a construction of a polymer composite material (carbon fiber) with AHC, another structure of the structure is proposed, where instead of AHC a filler based on a mixture of polymer films of the ABS type structure and energy material is used.
- At subsequent stages of the research, it is planned to conduct theoretical and experimental research on the possibilities of 3D-printing elements of the filler based on the optimum composition of polymer films and the energy of the material.

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