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REUSABLE SPACE PLANES CHALLENGES AND CONTROL PROBLEMS

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Abstract: The possible directions of development of space launch technology, including space launch to suborbital trajectory, in order to reduce the specific cost of launch at the expense of the majority of reusable carrier components, are analyzed. Opportunities of providing reusability for horizontal and vertical launch are compared. The experience of soft landing of the first stage of Falcon 9-R rocket of US firm SpaceX is taken into account. The requirements to the air breathing engine, which could provide an economical horizontal launch, are considered. The requirements for the engine could be reduced for sub-orbital launch, and in this simplified case they could be fulfilled well already at the present stage of development of aerospace technologies. The proposed principles of reusable HTHL system "WIG-craft +Aerospace Plane" are described and its advantages over the vertical launch systems are considered.

Keywords: space launch, specific cost, reusability, aerospace plane, rocket, WIG-craft, sea waves, flight control, relative motion control, docking, landing in the sea.

1. INTRODUCTION

Generally accepted critical operational task of modern astronautics development is to reduce the specific cost of payload delivery into orbit and removing astronauts as well as needed cargo from the orbit to the earth. The prospects of space exploration, and perhaps even a shift of some industries in the space, depend on success of such solution. For this purpose it is necessary to reduce the specific cost from the existing presently at global market value of about 12 thousand dollars per kilogram to a few times lower.

The main direction of reducing the cost of space launches is to move from expendable parts and constructions of the carrier and spacecraft to reusable ones. Space Shuttle project was the first to demonstrate the opportunity of construction and successful use of the reusable vehicle, but unfortunately has not proved the opportunity to reduce the cost of launches in the way of reusability.

What are the specific ways of reducing the launch costs, including the expense of reusability, exist today? Among the many concepts studied in different countries let us distinguish two approaches, and pay special attention to the automatic control problems associated with the implementation of such approaches.

The first approach is to implement a full-scale aerospace plane (ASP), using horizontal take-off, and not only horizontal landing. A key factor in this project is the usage of efficient air breathing engine capable to operate in a wide, up to really cosmic, range of speeds and altitudes. The ability to operate without oxygen supply by taking oxidant directly from the atmosphere can significantly reduce the specific cost of launch, but unfortunately a perfect air breathing engine has not been created until now. However, for a suborbital flight in the corresponding reduced requirements for a maximum speed, the required engine can be implemented now, and it can significantly affect the future development of astronautics.

The second approach considered here is to avoid the use of heavy wheeled undercarriage for ASP, the need for which is eliminated if the ASP performs launch and landing with the assistance of Wing-in-Ground effect (WIG) craft. The Russian name ekranoplane is used often for WIG-craft. The first few in the world heavy ekranoplanes with take-off mass 140-450t were designed and constructed under the order of Russian Navy. Unfortunately, at that time only analog control systems were designed and used for these vehicles. Presently the modern digital motion control systems could be more perfect.

2. PROVIDING OF REUSABILITY OF VERTICAL LAUNCH VEHICLE STAGES

The original approach to the problem of reusability was shown by the private US company SpaceX, which managed to land the returned first stage of the rocket Falcon 9 on the barge in ocean. It was performed successfully at April 8, 2016 and than twice in May. Before it in December 2015 this first stage was landed at the land surface, but landing at the offshore platform looks more attractive. It is shown in Fig.1 (Berger, 2015; Bradford, et al, 2014; Chang, 2015; Riley, 2016)

Since the cost of the first stage of the rocket is a major component of the cost of the launch, its repeated use can be really beneficial. It is not quite obvious that the benefit of falling rocket deceleration by using the rocket engine, not a parachute, exists, but it is clear that this case is considered

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Fig.1.The SpaceX first stage after landing

also as the option for landing on Mars. Perhaps installation of a parachute on the first stage of the rocket complicates the design of well-known and already repeatedly tested vehicle, and furthermore does not guarantee absence of damage to this stage at landing. Probably, the project will also provide increased structural strength of the first stage, which eliminates the need to rectify damage to the hull. In the main engines for the first stage soft landing, there is almost no need to install any additional hardware complex. As the only additional element that is used during this first stage landing, several landing gears fixing rocket vertically after landing may be considered.

Supply of some excess of fuel and oxidizer in relation to the take-off mode is needed also, but engines, other aggregates, and the stabilization system for keeping the vertical position already installed in the vehicle may be used without excess. Of course, in the mode of landing stage laws of angular stabilization (this control loop uses nine liquid rocket engine Merlin) differ from the launch mode because of smaller controlled vehicle specific mass distribution along the length of the body, but this does not require the use of any new (redundant with respect to the take-off mode) hardware solutions.

Of course, the motion control system of the first stage of rocket during the soft landing must be complicated with a subsystem of map-matching guidance to the desired point on the ground or on an offshore platform, to complete the landing on a prepared flat surface.

So, the described project SpaceX certainly does not allow to consider the problem of reusability to be solved, but emphasizes its importance and willingness of business to invest heavily in the development of space technology.

3. THE WINGED SYSTEM OF HORIZONTAL LAUNCH AND LANDING

The solution of reusability problem looks more natural when using the wing systems, i.e. the concept of aerospace plane. For regime of landing it is already proven in the projects “Space Shuttle” and “Buran”, although this phase of flight can offer new solutions that do not require special aerodromes (see. Section 4). For take-off mode, the concept of horizontal launch with a wide-range of velocities air breathing engine, in principle, is promising not only because of the possibility of rapid formation of the desired orbits for the executable mission, but also in the sense of natural reusability of each stage, equipped with wings.

Unfortunately, the various existing designs of air breathing engine do not allow them to be used during cosmic velocities. This makes it necessary to use wing units for rocket engines at least in the final stage of acceleration under speeds of more than 10M, especially in the upper atmosphere. In spite of numerous and expensive research and development, it failed to establish an effective air breathing engine (even a simple ramjet engine), which proved to be more efficient than rocket engine in the final stage of acceleration at high hypersonic speeds and rarefied atmosphere of high altitudes.

Therefore, the ideal concept of construction of single-stage aerospace plane with horizontal launch remains may be a long-term prospect, but unfortunately not the nearest reality. So far, only the three-stage ASP can be seen, in which the first stage - a heavy aircraft or WIG booster with subsonic engine, the second stage - a supersonic airplane with air breathing engine, and the third stage - the actual space plane with a rocket engine. Each of these steps can be reusable with aerodynamic descent on its wings, but the valuation of the development and implementation of horizontal launch system in comparison with the well-established system of vertical rocket launch is not so optimistic now to insist on the immediate development of a horizontal launch system.

Instead of it, as was already noted, SpaceX has decided to improve the system of vertical launch by ensuring a smooth descent and landing of the first stage of the rocket. Of course it is necessary to try to use any progressive developments in related areas to improve operational efficiency of space launch systems, including the development and improvement of WIG-craft projects. High expectations for rapid progress in the development of design technologies of heavy ekranoplanes should be associated with the activation of this work in the well-known Russian Alekseev`s design bureau.

4. PROJECTS OF WIG-CRAFT USE FOR SPACE LAUNCH ASSIST

The idea of WIG-craft application for ASP assist at starting and landing was firstly proposed in 1995 by A.Nebylov, N.Tomita and Y.Ohkami (Tomita, N., Nebylov, A.V. et al, 1996; Nebylov, 1998). Originally the efficiency of ASP acceleration by heavy WIG-craft up to the velocity of 600-700 km/h was justified. It was assumed that after it ASP could continue the own flight separately with the application of its air breathing engine. The mass of fueled ASP with a crew of 5 persons was estimated at 500 tons, the mass of