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AEROSPACE SYSTEMS "AERIAL LAUNCH" AT THE MODERN STAGE

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Abstract

The need for the emergence and use of aerospace systems (ASS) "Aerial launch" by the leading countries has been formulated. The types of ASS and the types of military space systems are revealed, as well as the connection between them. The functioning and perspective ASS "Aerial launch" with civil and military applications is analyzed. Based on a systematic analysis, a structure of ASS "Aerial launch" for the conditions of the Republic of Bulgaria, its advantages, disadvantages and main properties is proposed. Based on the performed modeling, a scheme of operation of ASS "Aerial launch" and stages of the flight of the MiG-29UB carrier aircraft for launching a nanosatellite (nanosatellites) into orbit in the conditions of our country is proposed.

Introduction

The name of the systems "Aerial launch" is associated with the launch into space of an aircraft launch vehicle (LV) with a satellite or satellites carried by an aerodynamic aircraft (AC), which performs a flight at an altitude of not less than 10,000 m in the atmosphere on Earth, as a result of which the satellite (satellites) are launched into orbit.

Unlike ground-based and sea-launched LV, air-launched ones do not have to traverse the densest layers of the atmosphere and consume a significant amount of fuel. In this case, starting from a carrier aircraft at a certain altitude, the LV reduces the loss of speed due to the fact that it does not pass through the lower dense layers of the atmosphere.

Account should also be taken of the fact that ground-based or sea-launched LV consumes a significant mass of fuel to reach the altitude and flight speed that an air-launched LV already has when launched by a carrier aircraft.

Another circumstance that contributes to the increasing relevance of the "Aerial launch" systems is that in the 90 s of the twentieth century, as a result of the rapid development of high technology, the concept of "small satellite" (small satellite) appeared. This term refers to an artificial satellite of the Earth (ASE) with

a relatively small mass and dimensions, which have been declining in recent years. At present, these miniaturized spacecraft (SCs), also known as cubesat, due to their several times lower value, reduced power consumption and time to create them compared to conventional satellites, are launched into orbit by means of LV dozens of satellites simultaneously.

According to the company "Arianaspace", the classification of small satellites by indicator "mass" is as follows: small satellite 500–100 kg; microsatellite 100–10 kg; nanosatellite 10–1 kg; picosatellite — less than 1 kg [3]. The small mass-size characteristics of these satellites ensure their placement on board aviation LVs.

As a result of the above, as well as the commercialization of space activity [9], in the last 20 years an unconventional approach to launching small satellites into orbit has been actively applied — through a system known as "Aerial launch". In this system, the role of the first stage of LV for launching a satellite (satellites) into orbit is played by the carrier aircraft. In particular, the set of functionally interconnected and co-operating carrier aircraft, aircraft carrier and satellite/s designed to be launched into orbit around the Earth, as well as ground command center and surveillance equipment, forms an ASS "Aerial launch".

During the operation of the ASS "Aerial launch", the small satellite (satellites) with a relatively small mass is taken out (brought out) in Low Earth Orbits up to an altitude of 600–800 km.

The concept of creation and use of small satellites has passed through various space programs in recent decades (TACSAT, ORS, System F6, etc.), on the basis of which it is corrected and improved [8].

Modern projects "Aerial Launch" have an innovative character, because they incorporate digital and other high technologies, including robotics excellence.

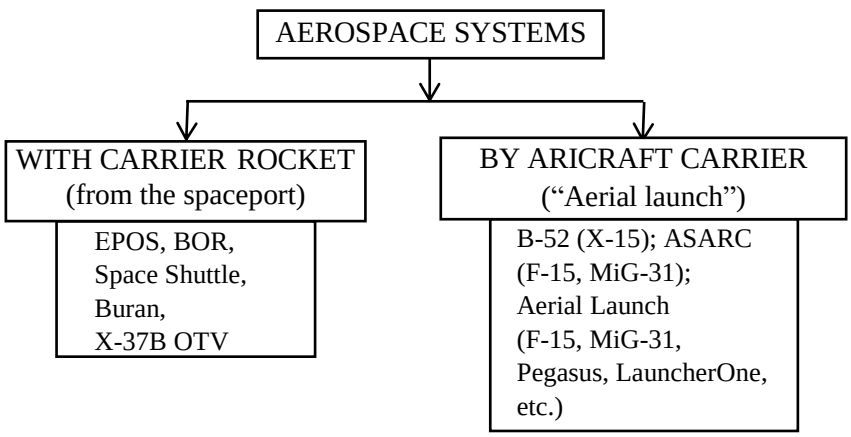

Fig. 1. Types of aerospace systems

In a broader sense, ASS operates not only with the use of carrier aircraft. Therefore, they can be considered as a set of functionally interconnected and coordinated operating aircraft carrier or classic LV, SC or rockets of the class "Air-to-Space", space and airport infrastructure designed to solve various target tasks in Space (Fig. 1).

These systems are created at the intersection of aviation and aerospace by combining the advantages and disadvantages of aircraft and missiles.

Problem status and area of research

In the early 60's of the twentieth century were gradually built, and in the following decades were established military space systems (MSS) of the United States and the Soviet Union (Fig. 2), representing a set of functionally interconnected and coordinated means of space, air and ground based designed to solve various target tasks of a military nature in and out of Space.

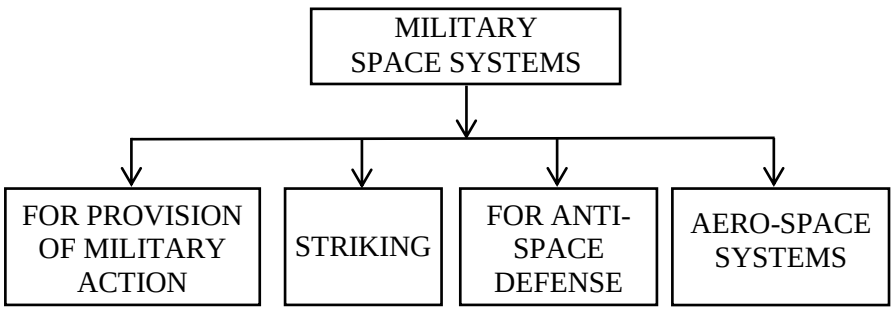

Fig. 2. Types of military space systems

Aerospace systems used for military purposes are the latest type of MSS.

In the early 60`s of the twentieth century in the United States began the actual construction of ASS as a type of MSS, whose main dynamic component is the manned missile aircraft X-15 (Fig. 3).

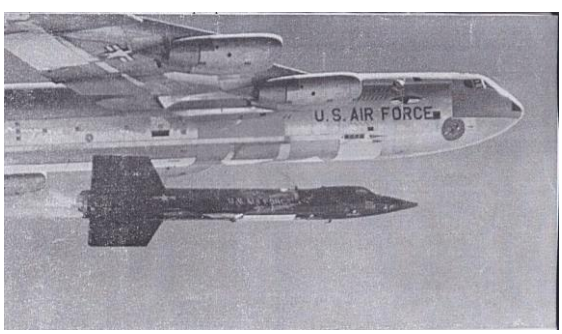

Fig. 3. Launch of the X-15A rocket plane from space by a B-52 carrier aircraft

This rocket plane (cosmoplane), mounted on a wing pylon on the right wing of a specially adapted B-52 bomber, is released at near-sonic speed by the carrier aircraft and from a height of 8.5 miles (13.7 km) at M = 0,8 launched into space by turning on its rocket engine [5]. The rocket plane reaches a hypersonic speed (about 7000 km/h) and an altitude of 80–108 km, and for this purpose its engine is turned on for up to 85 s. After reaching its dynamic ceiling, the X-15 rocket launches a ballistic descent, enters the dense layers of the atmosphere, performs planning, lowering and landing on two skis (rear chassis) and a landing gear on the bottom of a dried salt lake in the United States.

Similar activities for the creation of ASS are carried out in the USSR, finalized with the world's first automatic landing at an airport after a space flight on 15.11.1988 of the MSS for repeated use "Buran".

Simultaneously with the X-15 program, the Pentagon conducts research in the field of space defense and considers as one of the possible approaches to this issue the creation of an air-based anti-satellite missile system (ASARC), providing the launch of "Air-to-Space" missiles for destruction of SC. In the period from 1977 to 1986 on the basis of the F-15 fighter was created ASARC, known by the abbreviation ASAT (Anti-Satellite), whose full designation is ASM-135 ASAT. The complex [5] as a carrier aircraft includes the modernized F-15A fighter, armed with a two-stage solid propellant rocket and a small self-guided interceptor with an infrared self-targeting system for low-orbit spacecraft (Fig. 4).

Fig. 4. ASAT anti-satellite missile system with F-15A carrier aircraft

The range of the anti-satellite missile of ASARK "ASAT" is about 1000 km, and can intercept spacecraft at altitudes up to 560 km (350 miles) above the Earth's surface.

Of the modern "Aerial launch" programs for launching satellites into orbit via LV, the only one that really works is the American "Pegasus". For its realization, the launch of LV "Pegasus" is carried out by a specially equipped modified passenger plane L-1011 Stargazer of the company "Lockheed Corporation" (Fig. 5). The Pegasus launch vehicle is three-stage, runs on solid fuel and is located under the

fuselage of the launch aircraft, with a launch mass of 18,600 kg and a length of 15.5 m. The separation of the rocket from the aircraft is at an altitude of about 12,000 m at a speed corresponding to 0.8 M. The mass of the payload launched into low Earth orbit from the LV "Pegasus" is up to 360 kg.

Fig. 5. Separation of the Pegasus satellite launch vehicle from the L-1011 Stargazer to launch into space

The world's first launch of a satellite with air-launched LV took place on April 5, 1990. [5] The Pegasus launch vehicle of the American corporation Orbital Sciencec Corporation was launched by a modified B-52 bomber (from the X-15 Program), and the Pegsat and NavySat satellites were launched into low Earth orbit, respectively the Earth's magnetosphere and to ensure communication with the US Navy. The cost of launching this missile is about 11 million dollars.

The further launch of satellites under the Pegasus program is carried out by the new L-1011 Stargazer carrier of Lockheed Corporation. In April 1995, the first launch of the Pegasus-H rocket by the L-1011 Stargazer carrier was carried out.

The Orbital Sciences Corporation also created the LV Pegasus XL, which has an increased starting weight (23.13 tons) and length compared to the base model [5]. The payload mass, launched into low Earth orbit by the Pegasus XL, is up to 443 kg, and the release parameters of the rocket from the carrier aircraft (altitude and velocity) are close to those of the LV Pegasus. The cost of launching a satellite into space with a LV Pegasus XL is $ 40 million (as of 2014). Until October 11, 2019, inclusive, 44 launches of PH from the "Pegasus" series were performed, of which three were unsuccessful and two with partial success (in a lower orbit).

Of the ASS with LV, the most current at the present stage are the X-37B OTV space unmanned shuttles, which are essentially orbital aircraft launched into orbit using a classic LV from a spaceport and landing at an airport as an aircraft (Fig. 6). Their mission is shrouded in secrecy, and the sixth X-37B OTV reusable spacecraft, currently launched on May 17, 2020, is currently in space. These space unmanned shuttles largely replace aerospace ships repeated use of the Space Shuttle program after 2011.

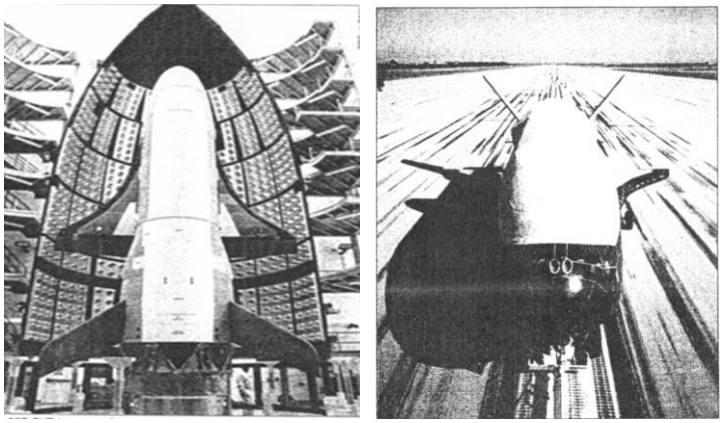

Fig. 6. Orbital plane reusable X-37B OTV, prepared for mounting rocket (left) and track the aerodrome (right)

The development of ASS “Aerial launch” with civil applications with solid fuel LV continues. The American company “Virgin Orbit” uses for this purpose a modified Boeing 747 aircraft, called “Cosmic Girl”, under whose left wing a two-stage LV “LauncherOne” with liquid fuel and a length of 21.3 m is suspended on a pylon. The payload that can bring this pH into a low orbit is about 500 kg, and in a polar or close to it — up to 300 kg. This allows the output of a solar synchronous orbit (SSO) up to 300 kg payload.

On May 25, 2020, Virgin Orbit performed a failed test in which the LV fell into the ocean. On January 17, 2021, a second successful experiment was performed, launching 10 small satellites into Earth orbit (Fig. 7). The Boeing 747 Cosmic Girl successfully separates the LauncherOne RN from its board with these 10 nanosatellites — experimental satellites of NASA’s ELaNa educational program.

Fig. 7. Launcher One successfully launched with 10 nanosatellites from Boeing 747 Cosmic Girl

According to experts from the company “Virgin Orbit”, if the scheme of operation of this ASS works successfully, it is planned to launch into Earth orbit satellites with a mass of up to 300 kg worth 12 million USD, which is possible at 10–12 space launches per year.

In the second decade of the XXI century, the Spanish company “Celestia Aerospace” began work on ASS for launching nanosatellites. The authors of the idea rely on the MiG-29UB carrier aircraft, ie of a two-seater training fighter, included in the SALS (Sagitarius Airborne Launch System).

According to the authors of the idea [10], the carrier rocket of nanosatellites is of two types: heavy, launching 16 nanosatellites and light — 4 nanosatellites (Fig. 8). The SALS system is expected to launch nanosatellites into orbit around the Earth at an altitude of 400–600 km. Each of the nanosatellites weighs up to 10 kg and is cubic in shape with an edge length of up to 10 inches (25.4 cm).

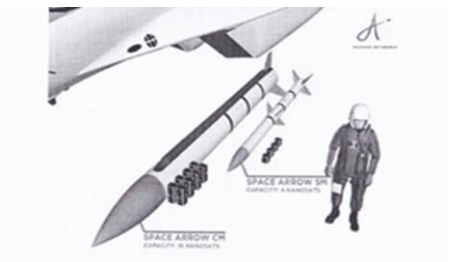

Fig. 8. Carrier aircraft MiG-29UB and both variants of satellite launch vehicle (according to “Celestia Aerospace”)

According to Celestia Aerospace, the use of the SALS system requires the MiG-29UB carrier with a LV under the wing to reach an altitude of up to 20,000 m after take-off from the airport. The conditions for the start of the LV, according to [4], are an altitude of 20,000 m; flight speed corresponding to M = 2.2 (i.e. supersonic start), as for the pitch angle the data are theoretical — 65°. At the pre-specified altitude, the Space Arrow SM/CM rocket is separated with its payload on board (i.e. nanosatellite or nanosatellites). Then the LV by starting its engine on solid fuel, and later by inertia, reaches an altitude of 400 to 600 km above the Earth in accordance with the flight program. At this estimated altitude, the nanosatellite (s) are separated and entered into orbit.

From the analysis of the considered issues in the civil and military spheres it follows that at the existing level of development of high technologies and for the considered aircraft-carriers, ASS “Aerial launch” can be an effective means of delivering payload to orbit around the Earth, if the mass it is up to 500 kg and the LV is hypersonic.

Research method

In order to realize the functioning of the ASS "Aerial launch", it should have the structure shown in Fig. 9. As can be seen, the ASS "Aerial launch" consists of interconnected components — components that together form its structure.

The main method for studying ASS "Aerial launch" is the theory of systems analysis.

The system has a purpose for which it functions, as well as management, thanks to which its constituent components function purposefully and coherently [7].

The structural connections of different nature between the components of the system ensure the preservation of the properties of the ASS "Aerial launch" when the conditions in the atmosphere and in space change.

The purpose of the ASS "Aerial launch" is the desired result of the operation of the system — launching into orbit a small satellite (satellites) with a specific purpose (e.g. observation).

The presence of management is an inalienable attribute of any system. For this purpose, ASS "Aerial launch" operates a management system at different hierarchical levels. In this case, the central control body is the ground command center (Fig. 9), connected with direct and feedback, both with the carrier aircraft and with ground (ship) surveillance means. At the carrier level, control is performed by the pilot, exchanging information with the ground command center on the necessary control effects.

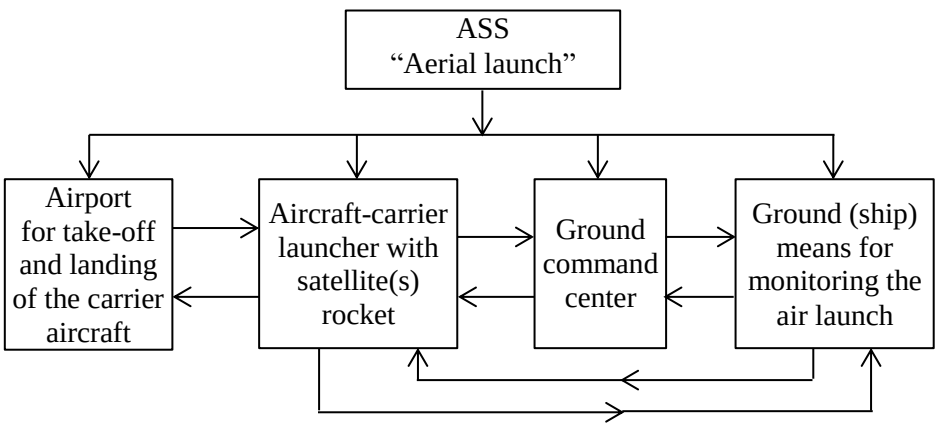

Fig. 9. ASS "Aerial launch" structure

The analysis of the state of the problem related to the functioning of various "Aerial launch" systems outlines the following advantages of ASS compared to traditional systems for launching satellites into Space:

- For the functioning of ASS it is not necessary to have or build a specialized stationary ground expensive infrastructure with numerous service personnel as a spaceport with its two main subsystems — technical complex and launch complex;

- Independence of the ASS from the geographical location at the start of the LV with a satellite (satellites) on board, i.e. ASS is not "attached" to the spaceport;

- Selection of the launch point and the possibility of launching satellites into orbit around the Earth in a wide range of directions (inclinations of the orbit to the plane of the equator);

- Use of the initial speed of the LV given by the carrier aircraft after its separation at the respective launch height;

- A significant reduction in the time required for the preparation and launch of aviation LV compared to traditional LV from a spaceport;

- Multiple use of the main components of the ASS;

- Several reductions in the cost of launching one kilogram of payload through the ASS compared to the traditional use of a launch complex from a three-stage LV spaceport;

- Reduction of the harmful impact of the exhaust gases from the LV of the ASS "Aerial launch" in comparison with the classic vertical start of the LV from the spaceport.

Regarding the advantage of ASS to reduce the value of launching one kilogram of payload, the analyzes show that according to [10], space activity becomes profitable by reducing the relative value of launching payload into space to values less than $ 3,000 per kilogram.

Along with the obvious advantages of the ASS over the traditional systems for launching satellites into space, there are certain disadvantages of the ASS "Aerial launch":

- The operation of the ASS ensures the launch of a limited payload into Space;

- The operation of the ASS ensures the launch of a satellite only in low Earth orbit;

- For the launch of a satellite from the ASS into higher orbits, a significant reduction in the mass of its payload is required;

- Complexity of calculations and the creation of aviation LV, the construction of which can withstand hypersonic speeds (aerodynamics, heating, thermal protection, etc.).

Based on the above advantages and disadvantages, the following properties of ASS "Aerial launch" can be defined and confirmed in practice:

- *Flexibility;*

- *Quick reaction to a created situation;*

- *Functioning in a time scale close to the real one;*

- *Multiple use of the main components of the system (the only one-time component is the LV of the aircraft);*

- A wide range of realized inclinations of the satellite's orbit to the plane of the Equator;

- Lower financial value of the aerial launch compared to the traditional launch in space from a spaceport;

- Environmental friendliness;

- Versatility, i.e. solving a wide class of tasks of civil and military nature.

Need for an aerospace system "Aerial launch" in the conditions of the Republic of Bulgaria

Our country has highly qualified space specialists and significant experience in the creation and use of space equipment, its own satellites "Bulgaria 1300-I", "Bulgaria 1300-II", "Meteor-Priroda", etc. [3], as well as in conducting space experiments. For all spacecraft and relevant space equipment in which there is Bulgarian participation, their launch into orbit in the past and now is carried out through foreign LV, as the Republic of Bulgaria does not have a spaceport with the relevant infrastructure.

When creating the ASS "Aerial launch", the Bulgarian Air Force not only owned and used MiG-29 fighters to solve various tasks, but also gained over 30 years of experience in the flight and technical operation of these aircraft. In addition, the country has developed airport infrastructure; there is a modern system for command and control of the Air Force; There is an anti-aircraft range of the Shabla Air Force, which is well situated geographically on the Black Sea coast, considerable experience has been gained from its use and, if necessary, temporary restrictions on navigation can be introduced.

Based on the above, it can be considered that for the conditions of the Republic of Bulgaria the project "Aerial launch" can be aimed at launching a low Earth orbit of a small satellite (satellites) for remote sensing through the appropriate LV, suspended under the body of the MiG-29UB (or if possible under the wing).

Most likely, the creation of the LV and its integration with the MiG-29UB carrier will be carried out in another country, due to the lack of experience in our country on this issue.

The creation of the small satellite/s can be done with the participation of Bulgarian scientists and specialists with experience in space research or on their behalf from another country.

The following merits of realization in the conditions of the Republic of Bulgaria of ASS "Aerial launch" with aircraft carrier MiG-29UB are outlined:

- The MiG-29UB training fighter, as a carrier aircraft and a main component of the ASS, is available for use in our country due to the fact that it has been mastered by the flight and engineering staff;

- The presence of two engines of the MiG-29UB aircraft, increasing its reliability, provide a high practical ceiling and the possibility of launching into orbit around the Earth a greater payload than that of a single-engine carrier aircraft;

- The larger geometric dimensions of the MiG-29UB aircraft in comparison with the single-engine fighters allow "suspension" under the body or wing of the LV with larger dimensions;

- Existence and accumulated experience in the use of the Shabla Air Force range, as well as its good location on the Black Sea coast in terms of possible missile launches;

- The crew of the MiG-29UB launch vehicle chooses the direction and the place of launch of the LV;

- There is a possibility for exporting the trajectory of the flight of the LV and the areas of fall of its detachable elements (exhaust stages, front fairings, etc.) from the territory of the Republic of Bulgaria over sea areas with limited navigation;

- Environmental safety (possibility to impose prohibition zones due to falling degrees of LV at its launch into space);

- Mobility of the ASS, enabling the launch of a satellite (s) into orbit from the territory of another applicant country, which is important for commercial launches, including at equatorial latitudes.

The disadvantages of the ASS with the MiG-29UB carrier in the conditions of the Republic of Bulgaria do not differ from those mentioned above for this system in the section "Research method" of the article.

From the above it is clear that for the successful operation of ASS "Aerial launch" in the conditions of the Republic of Bulgaria, in accordance with Fig. 9, it should be specified to the following components:

- Aviation (MiG-29UB carrier aircraft);

- Rocket (LV, respectively under the body or wing of the aircraft);

- Space (satellite/satellites, located at the front of the PH);

- Ground, including a command center or command post that processes incoming information and controls the carrier aircraft and ground (ship) surveillance equipment.

In February 2020, Space Research and Technology Institute-Bulgarian Academy of Science adopted a "Concept for the implementation of the Aerial Launch project for launching a small satellite (small satellites) into Earth orbit in the conditions of the Republic of Bulgaria" [5], as for the purpose is to model the trajectory of the MiG-29 carrier aircraft and the LV with a small satellite (small satellites). The analysis of the results shows [2–4] the theoretical possibility to use a MiG-29 aircraft and a solid fuel pH, with a length of not more than 4.5 m, with a mass of 600 or 1200 kg (in place of the undercarriage tank) for launching nanosatellites (1–10 kg) into low Earth orbit. The three conditions for launching the LV from the MiG-29 aircraft are altitude and flight speed and pitch angle of the

carrier aircraft when separating the LV with the satellite, depending on the flight mode.

Scheme of operation of ASS "Aerial launch" and flight stages for launching a small satellite (satellites) into orbit around the Earth in the conditions of the Republic of Bulgaria

The scheme of functioning of ASS "Aerial launch" in the conditions of our country includes the following stages:

- Preparation of LV, respectively of its three stages;
- Installation in LV of a payload — small satellite (small satellites);
- Pre-flight inspection and testing of the on-board LV systems and the small satellite (small satellites);
- Suspension of the LV under the body (half-wings) of the carrier aircraft and pre-flight inspection and testing of the LV systems and the aircraft;
- Departure of the MiG-29UB carrier from the airport and set to a height of 12,000 m – 13,000 m;
- Flight of the aircraft carrier MiG-29UB to the launch zone of the LV to Space, located in the area of the anti-aircraft range of the Air Force near Shabla;
- "Acceleration" by the aircraft carrier MiG-29UB at supersonic speed, performing the so-called. "Diving" with a negative pitch angle and subsequent set of heights (Fig. 10);
- Execution by the aircraft carrier MiG-29UB of the calculated dynamic maneuver "Gorka" (Fig. 10) and separation from the aircraft, for example by catapult or spring mechanism, of LV by actions of the pilot-operator;
- Reaching a safe distance and overshoot between the MiG-29UB carrier aircraft and LV (Fig. 10);
- Control of the flight of the aircraft carrier and LV before and after the launch area of the radar surveillance system of the Air Force;
- Autonomous start of the first stage of LV (Fig. 10);
- Separation of the first stage from the LV, its descent by parachute (or controllable flight to the area of fall) with a view to reuse and autonomous inclusion of its second stage (Fig. 10);
- Separation of the second stage from LV and autonomous inclusion of its third stage (Fig. 10);
- Reaching the third degree of LV at the first cosmic speed (and higher) and output of the calculated orbit of a small satellite (small satellites) — Fig.10;
- Flight of the carrier aircraft to the airport for landing and landing.

As can be seen from Fig. 10, the three conditions for launch of a missile module from a MiG-29UB aircraft, according to the performed modeling, are: altitude 15 km, number M = 0.9 and pitch angle 20°–25° at subsonic launch, and altitude 15 km, number M = 1.7 and pitch angle 30°–35° for supersonic start.

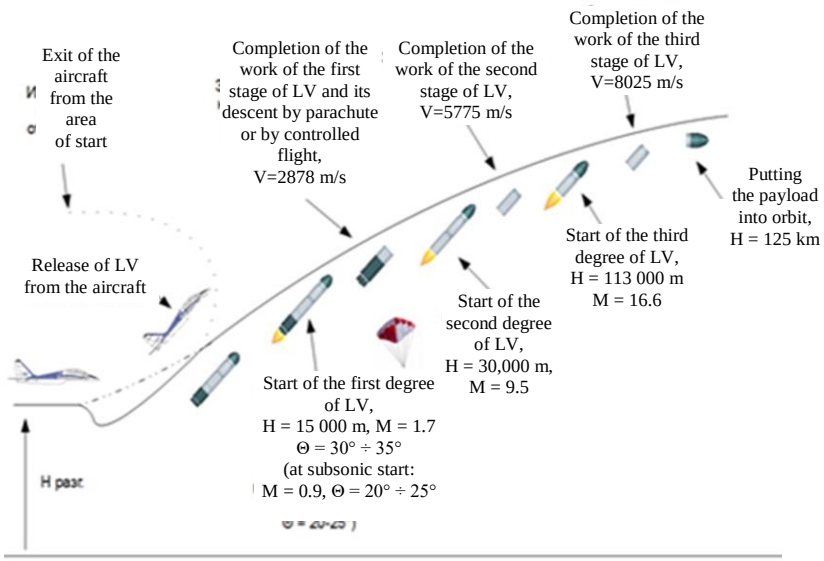

Fig. 10. Scheme of operation of ASS "Aerial launch" in supersonic flight mode of the MiG-29UB aircraft for launching the launch vehicle (continuous line) and in subsonic flight mode (broken line)

A detailed engineering and navigational calculation is needed to determine the mass of fuel on the carrier aircraft in order to be able to launch the LV.

Conclusion

The idea of implementing the "Aerial Launch" program to launch spacecraft into Low Earth Orbit over the past few decades, given current trends in space, is periodically proposed as a way to radically facilitate access to space for many countries.

The development of ASS "Aerial Launch" with civilian and military applications continues, which is associated with a series of successes and failures. According to Elon Reeve Musk, the success of the famous LV "Falcon 1" previously required at least four failed attempts.

The creation and use of the ASS "Aerial Launch" can reduce the cost of launching a payload and make space flights commercially efficient.

The relatively low value of the "Aerial Launch" project for the conditions of the Republic of Bulgaria is mainly related to the circumstances that its implementation envisages the use of already established reliable aviation equipment (MiG-29UB), which our country has had and successfully operated for decades, as

well as its own landfill with adjacent water area with a suitable geographical location, above which to realize its purpose ASS “Aerial Launch”.

The creation and operation of the ASS “Aerial Launch” is important not only in the launch of a small satellite (small satellites). Before launching a large satellite into space, scientists and specialists can check some of its equipment on a small satellite (cubsat) launched into orbit by the ASS “Aerial Launch”.

With the success of the “Aerial Launch” project, it is possible for the Republic of Bulgaria to independently launch small satellites into space in Low Earth Orbit, both for the needs of the country and at the request of other countries.

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АЕРОКОСМИЧЕСКИТЕ СИСТЕМИ „ВЪЗДУШЕН СТАРТ” НА СЪВРЕМЕННИЯ ЕТАП

П. Пенев, Н. Загорски

Резюме

Формулирана е необходимостта от появата и използването от водещите държави на аерокосмически системи (АКС) „Въздушен старт”. Разкрити са видовете АКС и видовете военнокосмически системи, както и връзката между тях. Анализирани са функциониращите и перспективни АКС „Въздушен старт” с граждански и военни приложения. На основата на системния анализ е предложена структура на АКС „Въздушен старт” за условията на Република България, нейните предимства, недостатъци и основни свойства. На базата на извършено моделиране е предложена схема на функциониране на АКС „Въздушен старт” и етапи на полета на самолет-носител МиГ-29УБ за извеждане на наноспътник (наноспътници) в околоземна орбита в условията на нашата страна.