Concept of aero-assisted rocket system for taking out mini- and microsatellites

Koncepcja wspomaganego lotniczo rakietowego systemu wynoszenia mini- i mikrosatelitów

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The article presents the concept of a low cost satellite launch system using single-shell anti-aircraft missiles and MiG-29 class aircraft. The authors have analyzed the possibilities of placing artificial Earth satellites available in the Republic of Poland with technologies and using currently available and planned in the near future to withdraw anti-aircraft missiles. The article presents the results of preliminary simulations and conclusions on the feasibility of the project.
KEYWORDS: aviation and cosmonautics, anti-aircraft missile, lifting artificial Earth satellites

Republic of Poland has no system of carrying out cargoes to orbit around Earth. The lack of the possibility of elevating micro or nanosatellites (fig. 1) into a low orbit – LEO (Low Earth Orbit) means that we do not have civilian or military communication or reconnaissance satellites. Although Poland can use European systems, such as the systems of the European Space Agency, or US, however, access to them is limited and very expensive.

For many reasons, it is justifiable to build your own cargo haulage system, which will become a factor of progress in the development of national cogeneration technology. As a result, Poland would achieve completely new capabilities in the field of space technology. Developing and analyzing the possibilities of such a system alone would create great opportunities for Polish technical universities and legal entities and companies that would like to invest their resources in the widely understood space segment.

In 2016, the WML WAT research team proposed the development of a unique cargo elevation system based on a system consisting of a carrier plane and a space rocket orbiter. In principle, the aircraft would serve as a platform for lifting a racket-rifle to a height of several thousand meters. After safe disassembly, its start would take place and after reaching a ceiling of 150÷250 km (depending on the needs), the rocket would release the payload (one larger or several smaller ones). Such systems have been developed earlier (including the American military system ASAT, F15GSE or commercial WhiteKnight-SpaceShip).

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Preliminary analysis showed that in Poland, as an aviation platform, a modernized MiG-29 aircraft (being in the equipment of the Polish Armed Forces) would be able to carry out a space rocket weighing up to 4000 kg, which would allow placing micro- or nano-satellites in orbit. Modernization of the MiG-29 airframe for the needs of the program is possible because in the country we provide full technological documentation of the aircraft as well as experience and repair facilities.
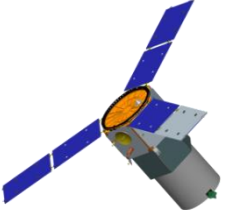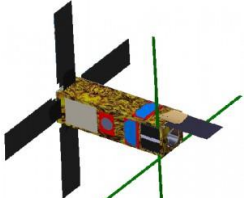
Microsatellites	10÷100 kg	XSS-10/11 OPAL TacSat-1 JWS-2 Microsat-70/100 Ofeq-3 Minisat-400 MiGhtySat II	
Nanoosatellites	1÷10 kg	FalconSat EyeSat MegSat SNAP ST-5 Microstar	

Fig. 1. Classification and examples of small satellites (based on: https:// ieeexplore.ieee.org/document/8303876/)

Problem of the air-assisted satellites elevation system

In the world, the concept of launching space rockets by airplanes and other objects (e.g. aerostats) has been analyzed for many years. In Poland, work initiated in 2016 by prof. Aleksandra Olejnik (WML WAT) were accepted for implementation by the author team (composed of: B. Machowski, P. Dobrzyński), who initially assessed the possibility of delivering cargoes to LEO orbits using rockets used by the Polish Armed Forces. The main focus was on the ceilings (flight trajectories) achieved by the anti-aircraft missiles S-75M, S-125 and S-200 for initial start conditions provided by the MiG-29 aircraft. The analysis of MiG-29 aircraft parameters shows that its useful mass is 7,580 kg, which in theory enables the load of the second stage of the 5W28E rocket with a mass m_R = 3918 kg and full tank fuel fueling (fig. 2).

Actual performance parameters of turbojet engines at high altitudes decrease significantly, which results from the fact that air density decreases ten times and air pressure – several times. This has a huge impact both on the reduction of the turbojet engine thrust and on increasing its demand for aviation fuel. For this reason, one of the considered variants of achieving high altitude by a plane carrying a space rocket is the use of a technique referred to as a zoom climb (fig. 3).

The zoom climb technique is a climb method in which a height greater than the height achieved thanks to the aircraft's thrust is achieved. In the first phase of the maneuver the aircraft accelerates to high speed in horizontal flight at a height at which the power of the engines is used in an optimal manner. Then, after reaching high speed, the plane begins to climb up by converting the kinetic energy of the translational motion into potential energy of altitude. This method differs from the steady climb method, where the increase in post-transitory energy results from the mechanical work done by turbojet engines, not from the kinetic energy of the aircraft. Zoom climbs are quite often performed by modern fighters.

Another problem is the need to carry out adaptation works in the carrier rocket itself, which may affect the complexity of the system and, hence, its cost-effectiveness. The authors of the concept propose modifying the on-board equipment, which is to ensure cooperation of the rocket with the flight path programming system based on data from the inertial navigation system and other sensors installed on the rocket.
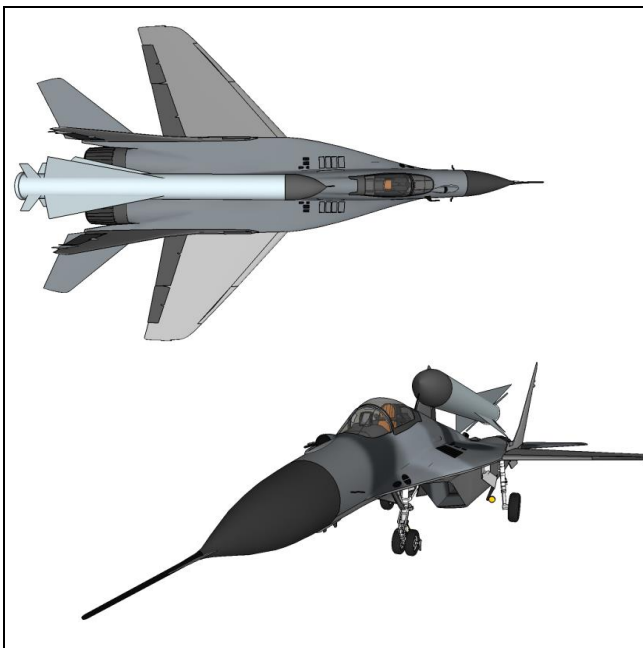

Fig. 2. Illustration of the proposed configuration of fastening the 5W28 missile on the MiG-29 aircraft
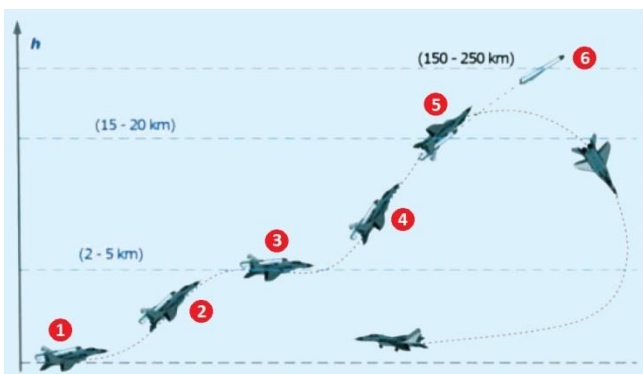

Fig. 3. Illustration of one of the scenarios for the air-assisted satellite launch: *1* – start and control of the rocket navigation system; *2* – classic climb to the level of safe acceleration; *3* – increasing the maximum speed; *4* – climb type; *5* – separation of the rocket from the carrier in reversed flight; *6* – separating the satellite from the rocket

The 5W28 rocket (fig. 4) is equipped with a 5D12 diesel engine powered by liquid TG-02 fuel and an AK-20 oxidant. The temperature of exhaust gases from the engine nozzle was 2500÷3000 °C. The motor has a 5F45 draft regulator. In simulation tests, its second mode was used, enabling the rocket engine to run for approx. 100 seconds. In the normal mode of 5W28 rocket set (driven by four starting engines, which after 3÷5 seconds finish work and give the rocket a speed of about 650 m/s) is located approx. 1000 m from the launcher.

Fig. 4. Rocket 5W28 PZR S-200WE at the start position (source: www.wzu.pl/sites/default/files/wega_wr_1.jpg)

Mathematical model used to simulate the flight of a space rocket

The mathematical model is a record of formulas describing the phenomenon studied. Single formulas or mathematical equations represent only a part of phenomena associated with the model of a flying machine, e.g. some of the patterns reflect only the functional dependence between parameters and nothing more. Mathematical models of flying objects are different depending on the design goals, although even for the same purpose, models may vary depending on the accuracy of the calculations. A frequent procedure is to replace each part of the flying object with a separate mathematical model. Differential equations can be used to determine the movement of a flying object, but the design details – related to ballistics or aerodynamics – determine the optimal parameters of a flying object.

The model omits lateral motion and motion effects, and the control system was adopted as ideal, which simplified the calculation considerably. In the considered satellite elevation approach, the simplified equations of motion of the center of mass of the flying object with respect to the inertial reference system (coordinate system related to Earth) were considered as a mathematical model [2–4]. Records resulting from the mathematical model were used to develop a simulation model – for its needs, a rocket engine model with a change in thrust, mass and mass change model and aerodynamic force coefficients were modeled, and the gravity model and atmosphere model up to 1000 km were adapted. The results of simulation tests for two variants (see table) are shown in figs. 5–7. The simulation time is limited to 120 s, which is 120% of the working time of the drive unit.

TABLE. Simulation conditions (including initial)

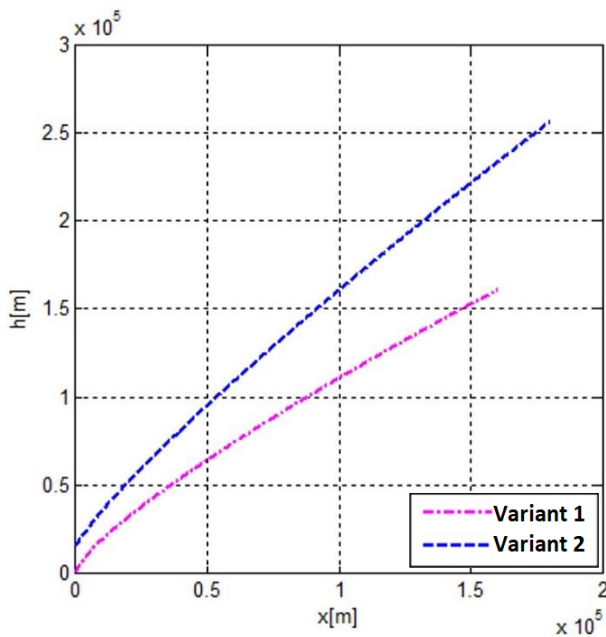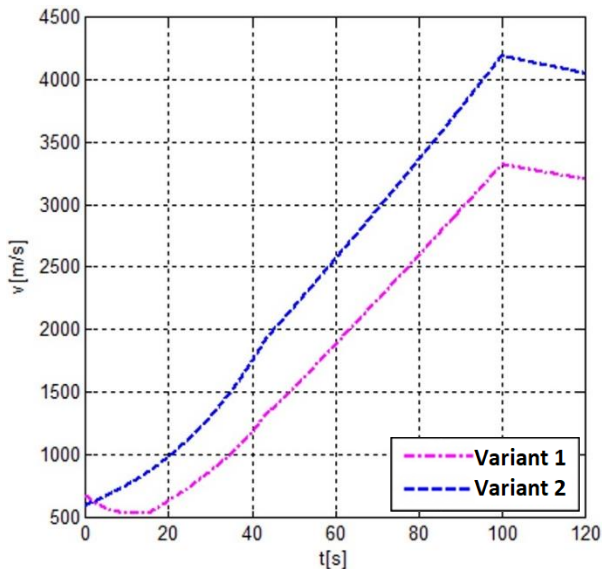| Variant description	Variant 1: simulation of launch conditions as from Earth, with the first stage	Variant 2: flight simulation for the initial conditions of takeoff after separation with the plane
x_0, m	0	0
y_0, m	700	15,000
v_0, m/s	675 (~2 Ma)	590 (~2 Ma)
θ_0, °	78	78

Fig. 5. Flight path of the 5W28 missile

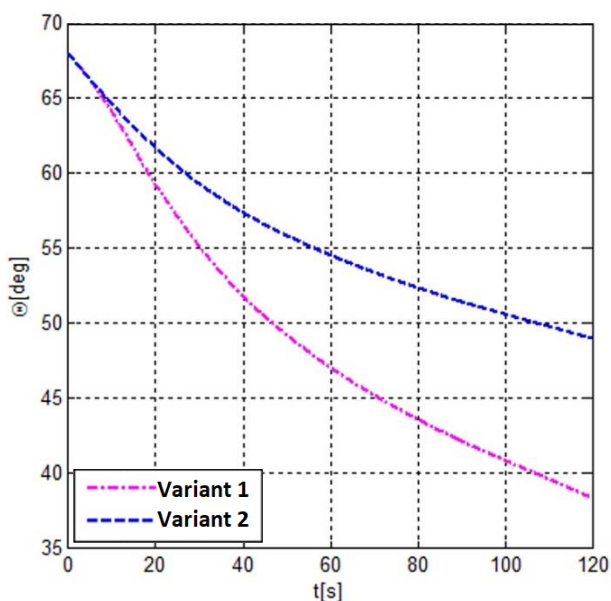Fig. 6. Flight speed of a 5W28 missile

Fig. 7. Angle of inclination of the velocity vector of the 5W28 missile

Conclusions

A feasibility study on the development of an aero assisted rocket launch project will answer the question whether modernizing the MiG-29 aircraft airplane and adjusting the 5W28 rocket in domestic conditions is possible. It will also indicate the threats in the implementation of the concept, will allow to assess the risk of feasibility and find alternative solutions. The results will be published in the form of a report for the Ministry of Defense and articles and papers for national conferences. These activities are part of such Ministry documents related to the directions of priority research, such as the document entitled "Priority research directions in the Ministry of National Defense for 2013–2022": 4.7. Groundbreaking technologies. Satellite technologies, including: microsatellites – space vehicles of the order of several centimeters and a mass of several hundred grams, enabling functioning in the sensor clusters and ensuring the acquisition of supervising and observing abilities. Priority – high".

The authors signal the need for commercial use of anti-aircraft missiles owned by the Ministry of National Defense, which after 2020 will have to be disposed of (or the previous times model – sold at the scrap price for profitable reselling to foreign entities on the secondary market).

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