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Air-rocket space launch system - as Responsive Space System

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Abstract

Objectives:The study was to analyze the concept of Responsive Space Systems alternative launch and set of the nanomicro satellites into Low Earth Orbit. The analysis focused on aircraft-rocket space systems, where platform for launching a rocket with a satellite is an aircraft.The aircraft in the role of the platform provides opportunities, system thus the operator doesn't need bases or space ports in European conditions.

Methods: Analysis of the research area, focused on the review, critical analysis, evaluation of the available literature, resources. The work was supplemented with the results and recommendation of the research project recently carried out at the MUT.

Results: Systems were presented in view of the war in Ukraine. Existing operational and currently designed systems were reviewed. Article evaluated the aerial-rocket systems for launching objects into the LEO in the context of the system's operational costs and capabilities, potential market and further military and civilian applications also the needs of the Polish Armed Forces. Combat aircraft and rocket kits based on decommissioned from PAF fighters were proposed and valuated.

Conclusions: Implementation of system gives autonomy from countries or companies offering space services, possibility of mastering new capabilities of placing satellite systems for security&defense purposes. For the PAF, aircraft-rocket kits based on phased-out supersonic combat aircraft may be the start of the development and constructionof the national Responsive Space System. The country's scientific-industrial base has competence to design&build such a system. Polish Space Agency can act as an integrator of the system just as NASA did in the 1960s.

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Introduction

Military operations in Ukraine have indicated how important satellite systems are from the point of view of conducting combat operations. Information from satellite imaging sources provides the opportunity to produce reliable information and data bases about, among other things, the location, activities of the enemy, elements of his infrastructure including military and critical, as well as the geographical environment, which directly affects the assessment of the enemy's potential and expands situational awareness on the battlefield. Another example of the type of satellite systems no less important from the point of view of security and defense are communication satellites - designed to receive, amplify and transmit signals. Already during the initial phase of Russian aggression, the Armed Forces of Ukraine received access to US systems, which consequently deprived Russia of the element of surprise and allowed it to successfully slow down and halt the Russian offensive, a spectacular event is Elon Musk's provision of Internet access through SpaceX's Starlink system.

The traditional and most widely used method of launching space cargo - satellites into Earth's orbit especially Low Earth Orbit (in short LEO) is to launch a carrier rocket from the surface of the Earth (land or sea). In addition to having a rocket tailored to perform a specific mission profile, such a method of space transportation requires space base (military) or a spaceport (commercial). Consisting of a complex ground infrastructure equipped with, among other things, the launch pads, a mission control and tracking system and an extensive security zone, the spaceport makes it possible to carry out rocket launches. In addition, the need to designate extensive, unpopulated safety zones around spaceports precludes the possibility of building such facilities in densely populated areas, such as Europe. The process of preparing and carrying out a launch mission in this way is time-consuming and very expensive. The development time for a conventional satellite ranges from 4 to as much as 10 years, for a micro satellite (10 to 50 kg) the time is one to four years. In contrast, the lead time for a dedicated mission to send a payload into space is one to three years (Cebrowski et al., 2005, Kulu 2021).

Intense technological advances are making it possible to construct ever smaller, more efficient and less expensive satellites. The availability of relatively inexpensive nano (up to 10 kg) or micro satellites is determining the growing interest in space exploration among private companies and government organizations or even universities. Unfortunately, despite the significant reduction in satellite weight, the cost of launching satellites is high relative to the cost of manufacturing the satellite itself. Of the 180 small payload (up to 1500 kg) launch systems analyzed, none can accomplish the mission for less than $2 million (Kesteren, 2013, Kulu, 2021). In order to reduce costs, small satellites (up to 100 kg) are most often not sent separately, but rather as an addition to the free payload space of the rocket, together with larger satellites, or other payloads, which are the main target of the mission (so-called piggy-back). Placing nano or micro satellites into orbit using shared payload space has many limitations. The launch time of a space rocket and its target orbit location is determined by the owner of the main payload. The waiting period for missions using shared payload space can be even longer than for dedicated missions. For this reason, precise placement of small satellites, in a short period of time, is often not possible. The commercial company SpaceX, for example, lifts orbital payloads of 10 tons or more using Falcon rockets. In this case, a "smaller" with a small payload customer has to wait for a large transport, or until the company "fills" the payloads, also the mission profile or target orbit is defined by the "principle" contractor.

1. Responsive space system

Increased interest in space exploration and the rapid growth of the small satellite industry require dedicated launch systems tailored to individual customer needs. The need to develop low-cost, mobile and flexible systems for launching small or micro satellites into orbits around the Earth on demand (at short notice) is determining increased research and military operations in this area. In the military nomenclature, these systems are classified as so-called Responsive Space Assets (Chen, et al. 2006, Clarke et al., 2007, Perry et al., 2021), i.e. alternative to traditional, space launch systems, i.e. low-cost, reliable, accessible and mobile. In the latter sense, it should be understood as systems that do not require extensive and permanent ground infrastructure for space rocket launch and control. In 2007, the Operationally Responsive Space Office (ORSO) was established in the United States to build a "tactical" system of small satellites for broad "support" of the armed forces. Another task is to put satellites into space "quickly" depending on developments, hence the English name responsive. One of the elements of the ORSO program is to be Responsive Spacelift Systems, i.e. systems for the launch by aerial platforms (aircraft) of space objects, here understood as space rockets, which will carry a satellite into the target orbit around the Earth, hence in the literature the name Air-Rocket (in this paper designated as AR in short) or Air-Launch space systems. ORSO includes not only all types of armed forces, but also: NASA, DARPA (Defense Advanced Research Projects Agency), MDA (Missile Defense Agency) and NRO

(National Reconnaissance Office). The participation of the latter organization testifies to the nature of ORSO's tasks.

As mentioned above, an alternative means of space transportation is the idea of launching payloads into earth's orbit using aircraft-rocket systems. The concept of mixed space transportation involves launching a space rocket with a payload from an aircraft or other platforms (e.g. balloons or airship) - a reusable carrier at a certain altitude above the Earth's surface. AR system makes it possible to launch, for example, small satellites while reducing ground infrastructure and costs. Such a method seems promising especially for countries without convenient conditions for creating their own spaceport. The use of aerial-rocket systems also means independence from weather conditions. Conventional launches often involve having to postpone the launch to another day due to unfavorable weather conditions. In contrast, a carrier aircraft is free to go to an area where weather conditions permit a mission.

In 2021, representatives of Virgin Orbital company (Perry et al., 2021) at “Joint Air & Space Power Conference, Delivering NATO Air & Space Power at the Speed of Relevance” presented a project addressed to NATO sates, to launch space rockets into polar orbit from European air bases or commercial airports, the list includes the Polish Air Force base in Malbork (Fig. 1, Table 1.).

Fig. 1. Air-launch “orbital access corridors” near NATO European member nations

Source: Perry et al., 2021

Table 1. NATO member countries who have potentially compatible airports that enable orbital access via Horizontal Air-Launch

Member Country	Candidate Spaceport	Approximate Orbital Access
Albania	Kuçovë Airbase	80^0 to SSO (Atlantic)
Belgium	Ursel Airbase	70^0 to SSO (North Sea, Atlantic)
Bulgaria	Burgas Airport	80^0 to SSO (Atlantic)
Canada	Mirabel Airport	80^0 to SSO (Arctic)

Croatia	Dubrovnik Airport	80^0 to SSO (Atlantic)
Denmark	Karup Airbase	70^0 to SSO (North Sea, Atlantic)
Estonia	ÄmariLennubaas Airbase	70^0 to SSO (North Sea, Atlantic)
France	Istres-Le Tubé Airbase	70^0 to SSO (North Sea, Atlantic)
France	Cayenne-Félix Eboué Airport	0^0 to SSO (French Guiana)
Germany	Rostock-Laage Airport	70^0 to SSO (North Sea, Atlantic)
Iceland	Keflavik International Airport	60^0 to SSO (Atlantic, Arctic)
Italy	Taranto-Grottaglie Airport	80^0 to SSO (Atlantic)
Latvia	Riga International Airport	70^0 to SSO (North Sea, Atlantic)
Netherlands	Amsterdam Airport Schiphol	70^0 to SSO (North Sea, Atlantic)
Netherlands	Curaçao	0^0 to SSO (Equatorial)
Norway	Andoya Spaceport	70^0 to SSO (Norwegian Sea)
Poland	Malbork 22nd Airbase	70^0 to SSO (North Sea, Atlantic)
Portugal	Santa Maria Airport (Azores)	50^0 to SSO (Atlantic)
Spain	Gran Canaria Airport	50^0 to SSO (Atlantic)
Turkey	Balıkesir Airport	80^0 to SSO (Atlantic)
United Kingdom	Newquay Airport (Spaceport Cornwall)	70^0 to SSO (North Sea, Atlantic)
United Kingdom	Overseas Stations (e.g. RAF Ascension Island)	0^0 to SSO
United Kingdom	Various Airports/Airbases (e.g. Anderson Air Force Base)	0^0 to SSO
* Nations requiring further analysis: Czech Republic, Hungary, Greece, Lithuania, Luxembourg, Montenegro, North Macedonia, Romania, Slovakia, Slovenia		

Source: Perry et al., 2021

Various concepts of airborne systems can be found in the literature, ranging from the use of stratospheric balloons, commercial passenger or transport jets, supersonic combat aircraft (retired from service) to next-generation hypersonic aircraft. Currently, there are two fully operational launch systems, but many are in development (Table 2).

Table 2. Overview of air-rocket space launch systems

System manufacturer	plane-platform	Rocket	payload in [kg]	number of launches performed	Current status of the program
Northrop Grumman	Lockheed L-1011	Pegasus XL	443	45	operational
Virgin Orbit	Boeing 747	Launcher One	300	3	operational
Launcher & Logistics	Boeing 747	-	-	-	stage of development
Stratolaunch Systems	Model 351 Stratolaunch	Pegasus XL/ Talon-A	450	-	stage of development
Astraeus	Boeing 757	-	800	-	stage of development
Orbit Boy	Il-76	-	200	-	stage of development
Celestia Aerospace	MiG-29		50	-	stage of development
Boeing	F-15E	ALASA	50	-	stage of development
RDC	MiG-31	-	-	-	stage of development

Source: compiled by Authors

2.1. Subsonic commercial aircraft

The US company Northrop Grumman (formerly Orbital Sciences Corporation) has developed the first private AR launch system for the Low Earth Orbit. The Stargazer - Pegasus system (Fig. 2) is designed to provide low-cost, efficient, and flexible space transportation especially for small, such as nano, micro or mini satellites (Orbital Sciences Corporation, 2009). The system uses the Pegasus family of rockets, which are carried by a specially modified "Stargazer" passenger jet (Lockheed L-1011 TriStar). The rocket is carried under the fuselage of the aircraft and is detached at an altitude of about 12 km above the ocean, at a speed of 0.82 Ma. The Pegasus XL rocket can carry up to 450 kg of payload to LEO, and its launch mass is 23,130 kg. The process of taking a payload to LEO takes about 10 minutes. The system is capable of carrying payloads to a wide range of orbits around the Earth. The efficiency of the system is convinced by the performance of 45 Pegasus rocket missions (2022). Northrop Grumman provides the ability to launch rockets from various locations on the ground using a minimum of ground equipment; the system's capabilities are used by the US Army and NASA, among others.

Fig. 2. "Stargazer" with Pegasus XL rocket during mission

Source: Orbital Sciences Corporation, 2009

A similar concept and the same method of carrying the rocket is used by Virgin Orbit's AR system (Fig. 3). Virgin Orbit's system uses the LauncherOne family of rockets, which are launched using a specially modified Boeing 747-400 passenger aircraft bearing the name "Cosmic Girl." The rocket, with a launch mass of 25,855 kg, is capable of carrying a payload of 300 kg into orbit, at an altitude of 500 km (Virgin Orbit, 2021).

Fig. 3. "Cosmic Girl" with LauncherOne rocket during mission
Source: Virgin Orbit, 2021

Unlike the Pegasus system, the LauncherOne rocket is hooked up under the wing of an aircraft using a specially designed adapter. Detachment of the rocket from occurs at an altitude of about 10 km, at a speed of 0.67 Ma. So far, Virgin Orbit has carried out 3 cargo launch missions . The cost of a single mission for this system is $12 million.

According to a NASA study (Bartolotta, et al., 2011), the most promising carrier aircraft model, for the concept of using a commercial jet, appears to be the Boeing

747-400F (Fig. 4). This model, due to its popularity, is readily available and has an optimal ratio of acquisition cost to payload capacity (about 9,000 kg per LEO). The double-body aircraft under consideration, such as the twin fuselage (Fig. 5.) Scaled Composites Model 351 Stratolaunch, first flight in April 2019 (Stratolaunch systems, 2022), despite the higher possible payload mass carried into orbit (about 24,000 kg per LEO), have higher acquisition and operating costs. Due to their dimensions, they also require wider runways, which limits the mobility of the system. Another carrier aircraft model under consideration was the Ukrainian Antonov An-225 Mriya (Bartolotta, et al., 2011), but it was destroyed by the Russians in February 2022, anyway the fleet smaller ones An-124 Ruslans is still operational.

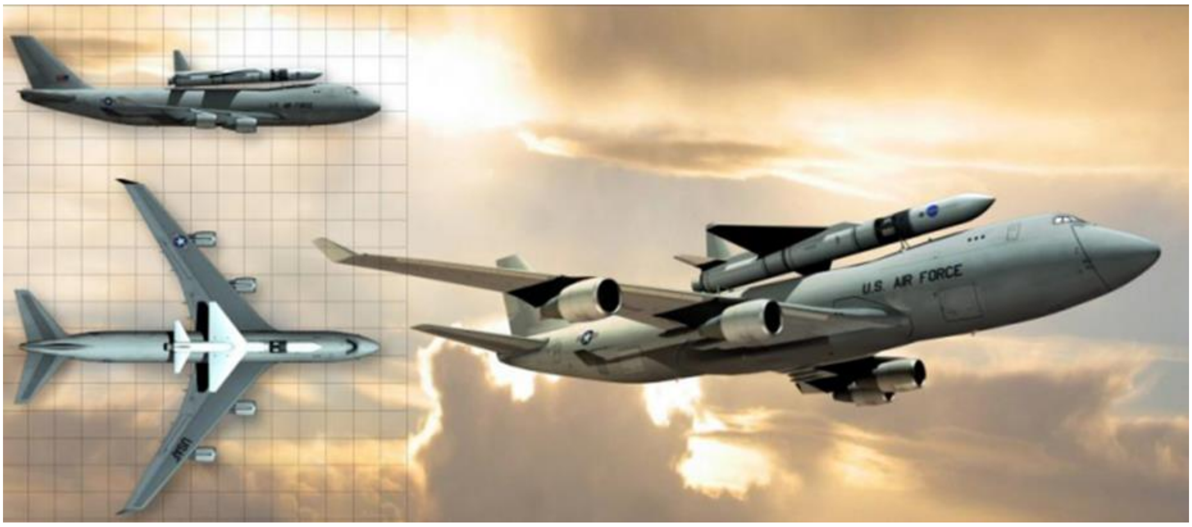

Fig. 4. Concept for placing a rocket on the back of a Boeing 747-400F

Source: Bartolotta, et al., 2011

Fig. 5. Twin-fuselage Stratolaunch airborne-carrier during roll out ceremony in 2015

Source: Stratolaunch systems, 2022

2.2.Supersonic combat aircraft

In 2006, the Boeing company presented (Chen et al., 2006) concepts for launching a rocket with a space payload on the back of a supersonic Boeing F-15E combat aircraft, as an alternative system to the "classic" one (Fig. 6). The upgraded rocket developed on the basis of the cited Pegasus with a mass of about 15,000 kg was to carry a payload of up to 300 kg (about 2% of the total mass of the rocket). This was a turning point in the development of the technology, as in the following years analogous projects appeared, in which decommissioned supersonic combat aircraft were proposed for space rocket launches: e.g. American F-15 and F-16, or Russian MiG-29 and MiG-31 (Chen et al., 2006, Kesteren 2013, Garcia, 2017, Smolyakov et al., 2018,). Recently, "start-ups" have emerged to seek investors to finance programs, one of them being Spain's Celestia Aerospace (Garcia, 2017), which envisages the use of MiG-29 aircraft for the role of carrier-platform. Most importantly, the system can use, after necessary modifications, existing aircraft designs, including available supersonic combat aircraft retired from military aviation . Currently, the so-called 4th generation of the combat aircraft are being phased out from military service widely (Su-22, MiG-29, F-15, or older versions of F-16).

Fig. 6. Evolution of Boeing's aircraft - rocket configurations, left: F-15 Global Strike Eagle with rocket on fuselage, right: F-15E ALASA with rocket under fuselage

Source: Chen et al., 2006

3. Responsive space system for the Polish Armed Forces

In order to develop an alternative space transportation system for Poland's needs, a research project was conducted at the Military University of Technology in 2018-2022 as a result of the project, the possibility of creating a low-cost system for launching satellites using resources and technologies available in Poland was evaluated. In order to reduce the unit cost of launching the payload, the possibility of using aircraft on the equipment of the Polish Air Force was considered: Su-22 and MiG-29. According to the announcement of the Minister of Defense, these aircraft should be withdrawn from service by 2025, so they can be used as aerial platforms. Preliminary analyses have shown that these aircraft are capable of carrying a space-rocket payload to an altitude of about 15,000 meters at supersonic speeds. The simulations made it possible to determine the profile and execution of the mission (Fig. 7, 8.) to launch cargo into LEO (Olejnik et al., 2020-2022, Zalewski 2022). In the considered configuration (Fig. 9.) aircraft will successfully perform the task set for them to carry a 2000 kg rocket with a space payload (microsatelitte) of at least 10 kg into LEO. Moreover, the analyses indicate that in addition to the cited airbase in Malbork (Perry et al., 2021)., the airbases in Miroslawiec or Swidwin could be used, in addition, there are still available decommissioned former airbases in ZegrzePomorskie or Debrzno, and former Soviet Army in Bagicz near Kolobrzeg (Fig.7.) or even commercial airports such as Szczecin-Goleniów Airport.

Fig. 7. Recommended the Polish Air Force airbases from which satellite launch operations could be conducted in polar orbit

Source: own study

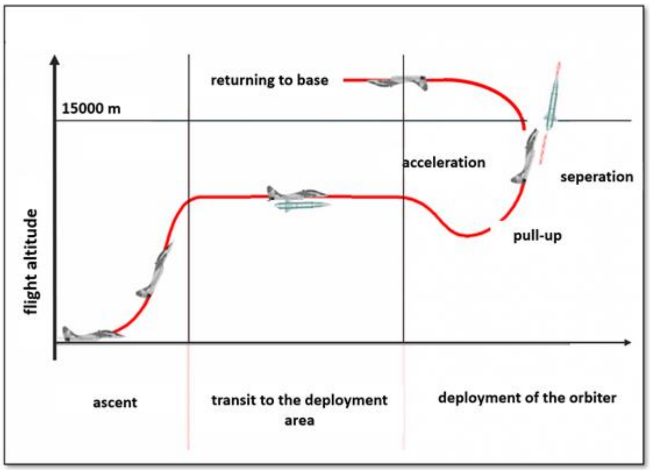

Fig. 8. Considered mission profiles of combat aircraft use for an air-launch-to-orbit payload delivery system.

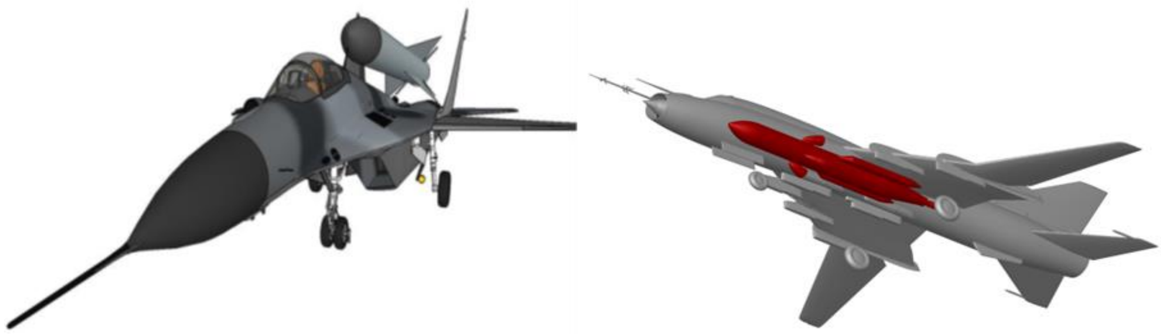

Fig. 9. 3D models of the tested aircraft-space rocket configurations (MiG-29 left, Su-22 right)

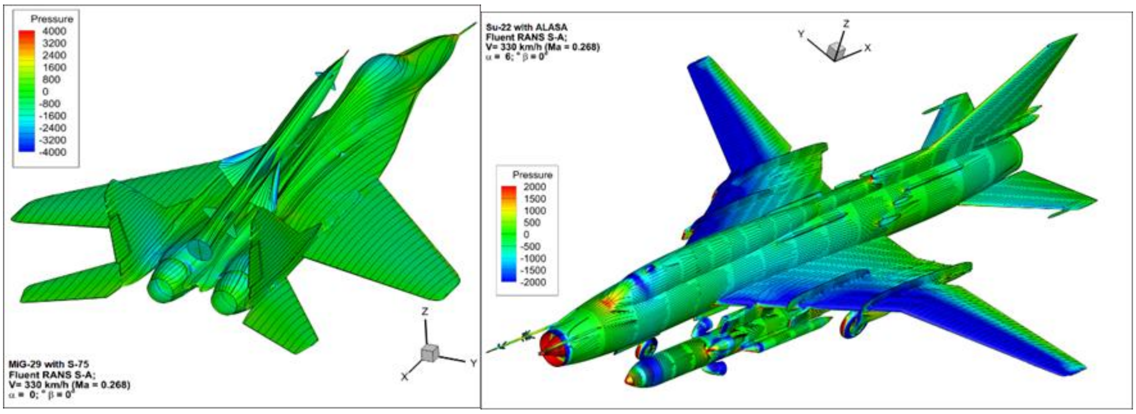

Fig. 10. Results of aerodynamic simulations of the investigated aircraft-rocket sets (MiG-29 left, Su-22 right).

For the cited MiG-29 and Su-22 aircraft, 3D digital models were made to study aeromechanical properties and real models (printed on 3D printers) to investigate the aerodynamic properties of the aircraft-rocket combinations. The results of computer simulations of aircraft-rocket set models indicate that the effect of the rocket on the change of aerodynamic characteristics of the aircraft is negligible, the presence of the carried rocket does not significantly affect the image of the flow field on the airframe of the aircraft and its stability in flight (Fig. 10). The simulations were verified by wind tunnel investigations (Fig. 11). Analyses of airframe strength structures also do not show significant changes in loading and stiffening of force components caused by carried space rockets. A conceptual design of a space rocket, to be carried under the fuselage of a MiG-29 aircraft, or the wing of a Su-22 aircraft, was also made (Fig.12). The project was supplemented by a risk analysis that considered, among other things, different configurations of space rockets. The risk analysis indicates that the risks to the success of the program are acceptable. Detailed results of the project are available (Olejnik et al., 2020-2022, Zalewski 2022).

Fig. 11. Wind tunnel investigations of the aircraft-rocket sets (MiG-29 left, Su-22 right)

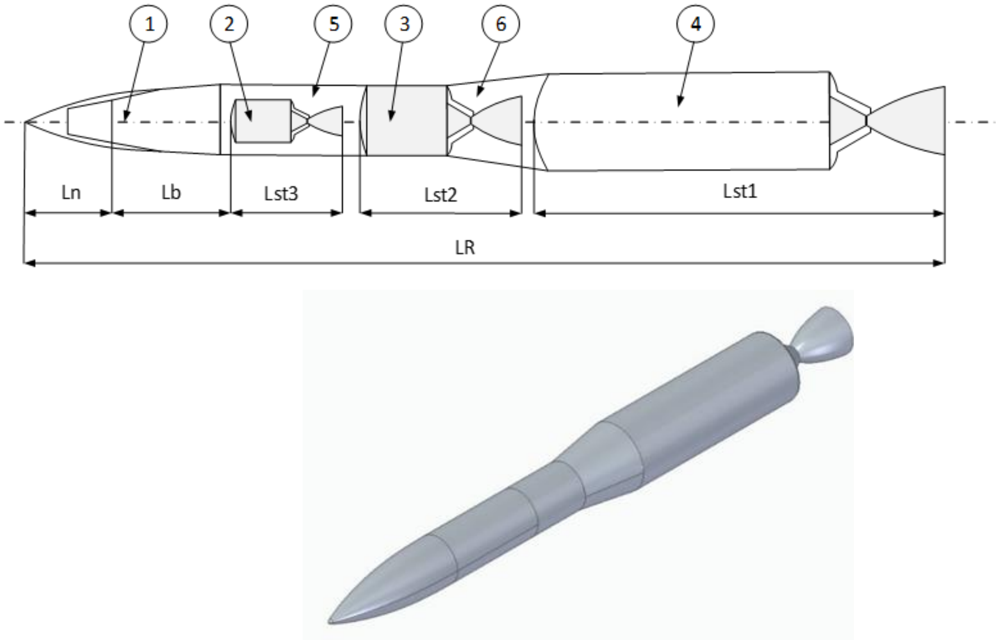

Fig. 12. Three-stage space rocket design

1 - nose section; 2, 3, 4 - rocket stages; 5, 6 - interstage support structures/

Conclusion

Air-launch systems, i.e. systems where the launch platform for a space rocket is an aircraft, do not require the construction of special ground-based launchers, infrastructure and safety zones of so-called spaceports, adding the idea of using the military's own retired fighter jets is a chance to become independent and create our own space programs.

It can be concluded that the country's technological and overhaul facilities have sufficient potential and experience to continue to maintain the aircraft in an airworthy condition and to modernize and adapt them to the needs of the program. This is primarily the Polish Armament Group and its affiliated Military Aviation Works, which has been repairing and modernizing aircraft for 30 years, but also the Institute of Aviation, which is working on rockets and has the potential to develop space rocket designs "tailored" to the capabilities and limitations of combat aircraft. Under the supervision of the Polish Space Agency (PALSA), an entire system could be developed in Poland, similar to what NASA did in the 1960s in the United States. What's more, the European Commission, as part of the European Defense Fund program (EF-2022), has advertised a call for proposals entitled Responsive space system, which proves that it is worth developing this niche.

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