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Development of Advanced Space Technologies and Systems as the Basis of Russia's Technological Sovereignty

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ABSTRACT

The relevance of this study is driven by the critical importance of developing high-tech and knowledge-intensive industries for the Russian economy. The article argues that scientific research and development in the space industry serve as both an indicator of Russia's scientific and technological progress and a subject of international competition. The results of space activities are in demand by a wide range of consumers. Space technologies are used as a tool for solving governmental and municipal management tasks. Services based on Earth observation sensing data from space have become an indispensable source of timely and relevant information for ensuring the operation of various sectors of the national economy. The study highlights that achieving technological sovereignty and leadership requires a comprehensive approach to the development and implementation of high-tech products and services, considering the mutually beneficial cooperation between the state and private companies. The author presents international experiences in implementing open data policies in the space sector, analyzes Russia's position in the global Earth observation market, and discusses promising space industry projects. The implementation of these projects could serve as one of the first examples of applying the private-public partnership mechanism in Russia's space sector.

Keywords: technological sovereignty; technological leadership; space industry; earth observation from space; open data; advanced space systems and services; private-public partnership

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INTRODUCTION

The development of high-tech, science-based sectors of the Russian economy is one of the priority tasks. Its solution is an important condition for the transition to an innovation economy, achieving technological sovereignty and ensuring national economic security. Technological sovereignty determines the level of the national independence achieved in the global priority high-tech science-based sectors, which ensures the implementation of national interests. According to the Concept of Technological Developments of the Russian Federation for the period up to 2030, technological sovereignty is understood as critical and cross-cutting technologies of the proper development lines and high-tech production facilities which ensure a stable capability of the State and society to achieve proper national development goals and materialise national interests.

Technological sovereignty exists in two main forms:

- research, development and implementation of critical and cross-cutting technologies (according to the established list);
- construction of high-tech products based on these technologies.[1]

Technological leadership, the achievement of which has been declared a national development goal of the Russian Federation for the period up to 2030 and in the perspective up to 2036, means technologies, technical and cost parameters of manufactured products significantly superior over foreign analogues. The transition from technological sovereignty to technological leadership within the framework of development of priority areas of the Russian Federation's economy requires the implementation of an integrated approach to the development and implementation of high-tech products and services, including effective interaction between the state and private companies in the implementation of projects in knowledge-intensive industries.

The space industry, as an established form of demonstration of the country's international prestige, is one of the priority sectors of technological development in the Russian Federation. According to the Article 2 of the Law of the Russian Federation "On the Space Activities"[2] it includes the areas shown in *Fig. 1*.

Space activities are defined as "all activities related to direct work on the exploration and use of the outer space, including the Moon and other celestial bodies".[3] The Russian Federation's rocket and space industry is represented by state and private enterprises engaged in the development and implementation of high-tech products: advanced satellites, rocket engines, space systems for earth observation from space, and so on. These enterprises reflect the level of technological development of the Russian economy and act as growth points of the high-tech sector, significantly increasing the competitiveness of our country in the global high-tech market.

The largest companies in the space industry are JSC Rocket and Space Corporation "Energia", which produces, among other things, modules for the Russian segment of the International Space Station; JSC Military-Industrial Corporation Scientific and Production Association of Machine Building, whose lineup of output products includes intercontinental ballistic missiles; JSC Rocket and Space Centre "Progress", which develops launch vehicles and satellites for earth observation from space; JSC State Space Research and Production Centre named after Khrunichev. JSC Khrunichev State Space Research and Production Centre, which have developed the new Angara family of space launch vehicles; JSC Reshetnev Information Satellite Systems, which is a leader on the Russian market in the segment of production of satellite for communication, television broadcasting, relay, navigation and geodesy; JSC Lavochkin Research and Produc-

[1] URL: https://docs.cntd.ru/document/1301657597

[2] URL: https://base.garant.ru/136323/

[3] Ibidem.

SPACE ACTIVITIES

- Scientific space research
- Space technology employed for communication, TV and radio broadcasting
- Earth sounding from the outer space including State environmental monitoring (State monitoring of the environment) and meteorology
- The use of satellite navigation and topographic systems
- Manned space flights
- The use of space technology, space materials and space technologies in the interests of the defense and security of the Russian Federation
- Observation of objects and phenomena in the outer space
- Testing of equipment in the outer space
- Production of materials and other products in the outer space
- Other types of activities carried out with the help of space technology

Fig. 1. **Areas of Space Activities**

Source: compiled by the author.

tion Association. JSC Lavochkin Research and Production Association, named after Lavochkin, is engaged in the production of space launch vehicles; JSC Russian Space Systems is engaged in the production of on-board equipment, equipment for space exploration, and the GLONASS satellite navigation system; JSC Research and Production Association "Energomash" named after Glushko is engaged in the production of rocket engines [1, p. 66].

In addition to state-run space companies, private companies also successfully operate in Russia. They design satellites, develop and operate space data receiving stations for low-orbit earth observation satellites, carry out operational monitoring of the Earth's surface, as well as develop and implement web GIS[4] and software.

The given analysis has revealed that different segments of the Russian space industry are developing very unevenly: "The sector specialised in Earth observation from space has a relatively modest position among other enterprises of the space industry. Nevertheless, space monitoring manufactured on the basis of Earth observation

[4] Web GIS is a type of geographic information system based on web-based data access technologies. A Geographic Information System (GIS) is a multi-functional system designed for the collection, processing, modelling and analysis of spatial data, its presentation and use for problem solving, preparation and decision-making within a company or organisation, as well as for integration into various websites and public portals.

from space data is actively used by the State and municipal administration, as well as a source of operational information for various sectors of the national economy" [2].

What is the Earth observation from space?

Earth observation from space is a process of observation of the Earth's surface by satellites equipped with various types of survey equipment. According to the Law of the Russian Federation "On Space Activities" dated 20.08.1993 No. 5663–1 (edition dated 22.07.2024 with amendments and additions dated 01.09. 2024), the Earth observation data is understood as "the primary data obtained directly by means of Earth observation equipment installed on board a satellite and transmitted or delivered to Earth from space by means of electromagnetic signals, photographic film, magnetic tape or by any other means, as well as materials obtained as a result of processing of primary data carried out to ensure the possibility of their use".[5]

The Earth observation from space industry consists of five main components, namely: satellites construction; satellites launch; operator activities for satellites control, planning and acquisition; distribution activities for the dissemination of primary information obtained from satellites; and the creation of "value-added products" based on primary information and their delivery to end users.

Figure 2 shows the scheme of Earth observation data acquisition from space, its processing and delivery to the end user.

The Earth observation results are in great demand in many sectors of the national economy, including energy, oil and gas, forestry and agriculture, cartography and land valuation, construction, etc. Government agencies use Earth observation data, for example, to prevent emergencies and control the elimination of their consequences, in the implementation of large infrastructure projects, in the inventory and accounting of regional property, in the identification of unregistered tax objects, as well as in the performance of re-surveying of landfills and in the monitoring of illegal economic activities. Space images data are in demand in the transport sector to monitor waste dumps, as well as in the process of controlling illegal economic activities. The advantages of using the earth observation method are the following: speed of data acquisition and its relevance at the moment of collection, high accuracy of processing, quality of information, economic feasibility. In addition, the level of use of such information by public authorities and business structures is one of the indicators of the successful use of the process of digital transformation of the Russian economy.

This industry has a long history. In 1960, for the first time in the USA, CORONA satellite system was launched, under the guidance of the CIA Science Directorate and with the support of the US Air Force. A powerful impetus for this practical implementation of such program was the launch of the first artificial satellite *Sputnik* into orbit by the Soviet Union in October 1957. This was the beginning of the era of space reconnaissance, which anticipated the creation of the industry of Earth observation from space. In 1962, the USSR launched the first reconnaissance satellite Zenit-2 into orbit. It was designed similarly to the manned spacecraft Vostok by the Special Design Bureau No. 1 founded for the Development of Long-Range Rockets, headed by S.P. Korolev. Subsequently, in the 1960s, the idea of creating a civilian satellite for scientific research of the Earth's surface emerged in the USA, followed by a satellite program for Earth observation from space to gather information on the planet's natural resources and global climate change.

LANDSAT PROGRAM

In 1970, the US National Aeronautics and Space Administration (NASA) received approval to develop satellites as part of the Landsat pro-

[5] URL: https://base.garant.ru/136323/

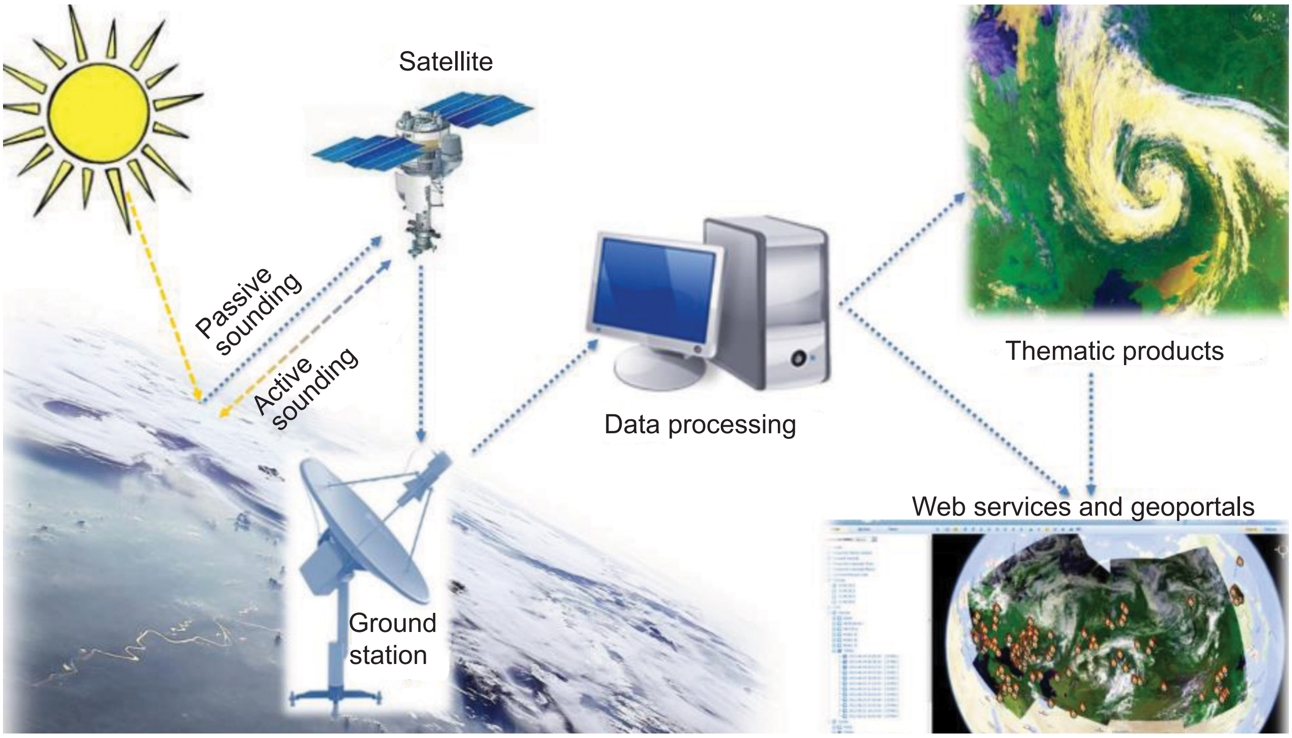

Fig. 2. **Diagram of Obtaining Earth observation Data, Processing it, and Delivering it to the End User**

Source: URL: http://mgmtmo.ru/edumat/satmet/ScanEx_2013.pdf

gram. The first of these series, Landsat 1, was launched in 1972 and was actively employed for public and research purposes until 1978 to be followed by Landsat 2 (1975–1983), Landsat 3 (1978–1983), Landsat 4 (1982–2001) and Landsat 5 (1984–2013). The currently active satellites still in orbit under this program are Landsat 7 (launched 1999), Landsat 8 and Landsat 9 (2013 and 2021 respectively).[6] By the year of 2030, the US plans to launch Landsat Next, a so-called constellation of three satellites. They are expects to be able to collect 15 times more data.[7] Today, they obtain the data used for agriculture and forestry, geology and cartography, detection of natural disasters, research and education.

The Landsat program in the United States has accumulated substantial archives of earth observation data, as shown in *Fig. 3*.

[6] URL: https://landsat.gsfc.nasa.gov/satellites/

[7] URL: https://landsat.gsfc.nasa.gov/satellites/landsat-next/

Landsat has become an example project of the Open Data policy. Since 2008, it has been freely accessible via Internet on-line connection on a non-discriminatory basis [3], which has contributed to the emergence of new technological solutions, the expansion of scientific research, business development, as well as the creation of services and operational applications for government agencies, as well as the private sector and civil society.

Russia in the global segment of Earth observation from space

Experts state, that the Russian Federation ranks fourth in the world after the United States, China and the United Kingdom with a significant lag behind the leaders in terms of the number of satellites in orbit. Russia's share in the world orbital constellation is less than 2.5 per cent [4]. According to experts, due to the intensification of international competition, by the year of 2030,

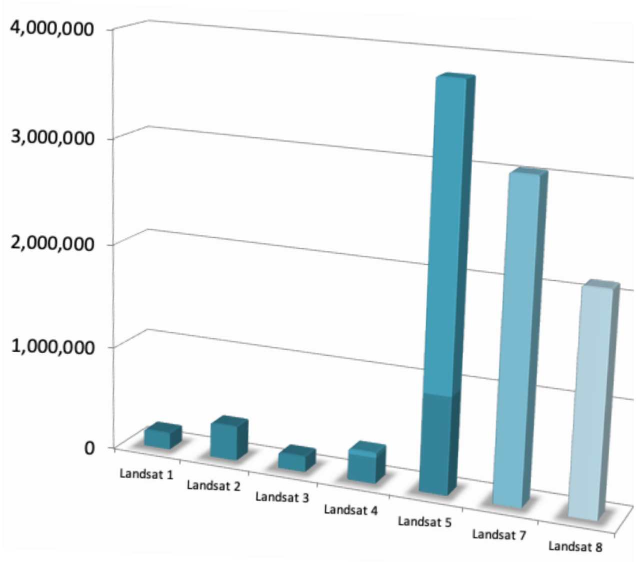

Fig. 3. **Landsat Data in the U.S. Archive (as of September 30, 2021)**

Source: URL: https://landsat.gsfc.nasa.gov/satellites/landsat-9/

the volume of the global market for Earth observation data will grow more than three times compared to 2020.

According to the global statistics, as a whole, 319 earth observation satellites were launched worldwide by 2023 [5, p. 5], of which 301 are still operating successfully by now. China and the USA take on the leadership in the production and operational management of Earth observation space systems. In 2023, China launched 119 satellites (40 per cent of the total) and the USA 103 (34 per cent) [4, p. 5].

The Russian Federation has put into orbit 9 earth observation satellites [4, p. 5], which makes nearly 3 per cent of their total number in orbit. In the segment of Earth observation from space, the Russian Federation has the following series of satellites Resurs-P, Kanopus-V, Meteor-M, Elektro-L, Arktika-M, Kondor-FKA.[8]

The outer space monitoring carried out by the Resurs-P complex is aimed for the research purposes and control measures to obtain data by means of "exploration of natural resources; control of environmental pollution and degradation, identification and study of environmental contamination, control of water protection and protected areas; information support for the search for mineral resources; assessment of ice conditions; inventory of natural resources to ensure rational activities in various sectors of the economy; monitoring of emergency situations; information support for engineering surveys; creation and updating of cadastral, topographic and navigational maps; determination of the type and condition of vegetation, the composition of the pollution film on the surface of the water, identification of minerals, soils; detection of illegal crops of drugs and controlling their eradication, etc."[9] The Ministry of the Russian Federation for Civil Defence, Emergencies and Elimination of Consequences of Natural Disasters, Ministry of Natural Resources and Environment of the Russian Federation, Roshydromet, as well as commercial entities, obtain the data from the Kanopus-V series comet satellites as a valuable source of information. Low-orbiting meteorological satellites Meteor-M series are designed to "receive space data for operational meteorology, hydrology, agro-meteorology, climate and environmental monitoring, including near-Earth space".[10] The main mission of the Electro-L geostationary hydrometeorological space complex is to provide data obtained related to synoptic analysis, global weather forecasting and forecasting for aviation, climate change monitoring and environmental control in industrial areas. The Arktika-M series of satellites provide "round-the-clock all-weather monitoring of the Earth's surface and the Arctic Ocean waters, as well as continuous and reliable communications and other telecommunications services".[11] The only radar satellite, Kondor-FKA, launched in

[8] URL: https://ntsomz.ru/remote_sensing_spacecraft/; URL: https://www.roscosmos.ru/24707/

[9] URL: https://www.roscosmos.ru/24984/

[10] URL: https://www.roscosmos.ru/37906/

[11] URL: https://www.roscosmos.ru/28966/

the year of 2023, provide all-round-weather monitoring throughout the Earth's surface.

However, the existing Russian equipment does not fully meet the needs of domestic users. The information obtained from foreign providers is quite expensive. Besides, the access to some information from abroad is severely restricted due to anti-Russian sanctions and the terms of licensing agreements. For example, in 2022, the largest foreign operators of earth observation from space: Maxar Intelligence[12] (USA), Airbus Defence & Space[13] (France), SI Imaging Services[14] (South Korea), Deimos Imaging[15] (Spain), and Capella Space[16] (USA), etc., stopped providing space image data to the Russian Federation [6]. This resulted in a significant deficit of data needed for effective functioning of domestic government agencies and commercial enterprises in various sectors of the economy. Insufficient resource support, as well as lack of appropriate knowledge, skills and abilities, backward ways to obtain information in the field under study, underestimated effectiveness of using Earth observation technologies can lead to untimely forecasting, detection and prevention of emergency situations, internal and external threats to food security, etc. Therefore, it is necessary to provide government agencies and commercial enterprises with information obtained from Russian satellites, which requires expanding the Russian fleet of Earth observation satellites.

[12] Maxar Intelligence is a US company that has developed the latest WorldView Legion satellites for high quality Earth observation.

[13] Airbus Defence & Space is a division of the Airbus Group responsible for defence, space products and services.

[14] SI Imaging Services is the provider of earth observation data from Korea's KOMPSAT series of satellites (KOMPSAT-2, KOMPSAT-3 optoelectronic satellites and KOMPSAT-5 radar satellite).

[15] Deimos Imaging is the company, which was founded as a result of collaboration between the Spanish aerospace company Deimos Space and the Earth observation Laboratory of the University of Valladolid. It develops, implements, operates and commercialises the Earth observation systems.

[16] Capella Space, also called called Capella 36, is an American aerospace company specialising in earth observation from space, mainly for defence and security purposes; high periodicity is achieved be means of the phased deployment of an orbital constellation of 36 radar observation satellites.

According to experts, "the development of the production capabilities of the rocket and space industry, the introduction of assembly-line production and the involvement of private companies in the development of satellite will make it possible to increase the scale of the Russian orbital constellation by 15 times by the year of 2036".[17] According to the Unified Plan for Achieving the National Development Goals of the Russian Federation to 2030 and in the Perspective to 2036, "the key factor to obtain technological independence in the field of advanced space technologies and services will be to ensure, that the Russian Federation achieves technological leadership in space activities, including by increasing the production of Russian satellites as a result of commissioning assembly lines in the rocket and space industry enterprises".[18]

Promising space systems and services

One of the global trends is the involvement of the skills and capabilities of the private sector in solving government tasks. For example, the private-public partnership model is typical for the space industries in some countries: for example, the US Department of Defence successfully operates in the field of Earth observation from space. The key factor to the implementation of private-public partnership for the space industry projects is the availability of developments and specific competences for private companies needed by the State to provide high-quality public services, which in turn stimulates research and development and the innovation process in the industry as a whole. In addition, such mechanisms can achieve greater feedback on research financing and successfully maintain the issue of subsequent commercialisation of results.

Today, the US space industry most actively accomplish the projects of the private-public

[17] URL: https://www.interfax.ru/russia/938056

[18] URL: https://base.garant.ru/411256963/

partnership model in the areas of satellite telecommunications, Earth observation, and space transportation. "In the recent years, the private-public partnership model mechanisms in the US have been actively improving and acquiring new features due to the sharp increase in the number of participants in space activities and the range of services they provide" [7, p. 80].

To achieve acceleration of technological development, national technological sovereignty and technological leadership of the Russian Federation in the international arena, a high-tech direction roadmap "Advanced space systems and services" for the period up to 2030[19] was approved by the Decision of the Presidium of the Governmental Commission for Economic Modernisation and Innovative Development of Russia No. 2 dated 29.12.2022. In order to implement it, the Government of the Russian Federation has issued Order # 3926-r of 15.12.2022 "On Approval of the Standard Form of Memorandum of Understanding between the Government of the Russian Federation and an Interested Organisation for the Development of a High-Tech District".[20]

The total amount of funding for all activities of the roadmap until 2030 is planned to

be nearly 480 billion roubles, including about 370 billion roubles from the budget and the rest from extra-budgetary sources. Part of the state funds will go to purchase Earth observation data from private companies, which in turn will have to invest in the development of new satellites. By the year of 2030, more than 60 Earth observation satellites and over 700 communications satellites are expected to be in orbit [8].

Another promising direction of the Russian space industry aimed at achieving technological sovereignty may be the Sphere project. Within the framework of this project, orbital communication constellations will be created with Yamal,[21] Express, Express-RV,[22] Skif[23] and Marathon,[24] as well as orbital constellations for Earth observation with optical-electronic and radar observation satellites

Pixel-VR, Berkut-VD,[25] Berkut-X,[26] Berkut-XLP, Berkut-C[27] and Smotr.[28] Thus, the launch of 360 satellites is planned by 2030, which will provide full coverage of the country's territory with all modern space services.

CONCLUSIONS

Nowadays, the Russian space industry is facing the challenges of significant expanding of the use of key space services for citizens, government agencies and business companies, in the spheres to provide high-quality communications coverage of the entire territory of the Russian Federation and geo-information products and Earth observation technologies. The comprehensive use of space monitoring tools opens up

[19] URL: https://www.roscosmos.ru/media/files/2023/perspektivnie.kosmiceskie.sistemi.i.servisi.pdf

[20] URL: https://www.consultant.ru/document/cons_doc_LAW_434521/

[21] "Yamal" is the common brand name for geostationary communications and direct broadcast television satellites owned by Gazprom Space Systems JSC. One of the promising Yamal-502 satellites to be launched in 2028 and provide satellite broadband services for mass users and communications for mobile projects, such as commercial aviation, shipping, road and rail transport.

[22] Express-RVs are advanced satellites developed by Information Satellite Systems named after Academician M.F. Reshetnev, that will provide communications, including broadband Internet access throughout Russia and the Arctic Ocean. The launch of the first satellite planned for October 2025, deployment of the full orbital constellation planned for 2026.

[23] Skif is a satellite communications system designed to provide broadband internet access.

[24] Marathon is a series of advanced satellite designed to organise data transmission around the Earth. The full Marathon orbital constellation will include more than 260 satellites.

[25] Berkut-VD is a promising space system for operational monitoring of the Earth's surface with a linear resolution of 1 metre.

[26] Berkut-X is a promising space system for all-weather radar monitoring of ice conditions on the Northern Sea Route, including control of hazardous production facilities.

[27] Berkut-S is a promising low-orbit satellite communications system for data exchange between automated objects in the Earth segment and for high-speed access to information networks, including the use of subscriber equipment operating in cellular networks.

[28] Smotr is a promising space system for highly detailed observation and monitoring of greenhouse gas emissions and methane leakage; URL: https://www.roscosmos.ru/39138/

opportunities to solve more effectively tasks in the area of the State and municipal administration, territorial organisation and development of transport and logistics corridors, solving environmental problems and development of various economic sectors, including such promising industries as robotics, data economy, etc. The use of space monitoring tools opens opportunities for more effective solutions of tasks in the area of state and municipal administration, territorial organisation and development of transport and logistics corridors. In the interests of the State, the economic efficiency of the use of information obtained by Earth observation from space will reduce labour costs and shorten time to obtain information on territorial processes and make management decisions, including in crisis situations. It will increase tax revenues from the use of resources, real estate complexes, or land, increase in efficiency, effectiveness and quality of State and municipal management, information openness, as well as the attractiveness of investment and the competitiveness of the regions.

In order to achieve the abovementioned tasks it is necessary to:

- increase furthermore the output of the orbital constellation of satellites, including specialised in Earth observation;
- implement the idea of conveyor production of satellites, which will reduce the cost, labour intensity and time for construction of satellites;
- implement private-public partnership projects in the space industry to attract investments and skills from private companies.

Successful implementation of these promising projects for the Russian Federation may ensure independence in providing government agencies and private companies with the necessary space data and services, as well as achieving technological sovereignty in one of the key sectors of the Russian economy.

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