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Insight into Military, Civilian, and Commercial Integration in U.S. Space Infrastructure Development

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Abstract: Space infrastructure has become the core area of military, civil, and commercial integration. This study uses a literature review and an intelligence analysis to summarize the status and development trend of space infrastructure in the United States (U.S.) and thoroughly analyze military, civil, and commercial integration from the viewpoints of top-level strategies, policies, and regulations, as well as organizational management. Several successful examples from the U.S. are summarized to provide a useful reference for the planning and construction of space infrastructure in China. To promote military, civil and commercial integration of space infrastructure, China should undertake overall planning at the national level, establish a specialized agency to coordinate with agencies related to space infrastructure construction and application, strengthen the research and development of satellite application technologies to establish the technological foundation for equipment development, and improve the policy and law systems to provide policy guarantee.

Keywords: space infrastructure; military, civil and commercial integration; development trend; United States

1 Introduction

Space infrastructure is essential for using space resources, expanding the scope of human activities and providing long, continuous, steady, and systematic public services to achieve goals such as national security, economic and social development, and technological progress, as well as to improve people's livelihood. Space infrastructure is an engineering system composed of aircraft systems that are to be operated in outer space (including adjacent space) and equipment that provide ground support. Promoting military–civilian integration in space infrastructure has a strategical significance. On one hand, construction and operation costs of space infrastructure are quite high and military–civilian integration will effectively alleviate the economic burden. On the other hand, space activities rely on private enterprises that develop military technology and also promote the civil value of related technologies.

With the continuous promotion of the "military–civilian integration" strategy [1], the principle behind military, civil, and commercial integration of the space infrastructure changed from following "military needs at the core and civilian–commercial services to the military" to realizing "full-element, multi-domain, cross-sector integration in the dimensions of top-level organizational management, systems design, and application services" in the United

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States (U.S.). In terms of system composition, there are no longer any independent satellite systems. Instead, there exist systems of space–ground integration composed of multiple-application spacecraft distributed in different orbits and possessing different functions along with ground application systems. In terms of system construction, the focus is not on "one star, one discussion," but on the overall planning and promotion. Further, in terms of system application, the U.S. has shifted from experimental applications to emphasized, standardized, and large-scale product services to drive industrial development.

Extensive research has been conducted on military, civil, and commercial integration and space infrastructure and valuable results have been obtained. In 1994, military–civilian integration was defined by the Office of Technology Assessment to involve processes of combing the defense-related with the civil science and technology to form a unified national science and technology industry. In other words, defense and industries utilize common technologies, processes, labor, equipment, materials, and facilities in order to satisfy both military and civil needs [2]. In the 1990s, the integration of the military and civilian industrial foundations was first proposed in *Technology and National Interest* by the US National Science and Technology Council (NSTC) [3]. According to this proposal, it was suggested that the separation of military and civilian industrial foundations is not sustainable and that an industrial foundation that satisfies both these needs is necessary. This was considered essential to achieve accelerated development of defense-related science and technology that uses high-tech civilian industrial foundation in the U.S. In 2000, China had adopted space infrastructure [4]. In 2001, the connotation of space infrastructure was elaborated by academician Wang XJ. Space infrastructure is essential for appropriately utilizing space resources. Such an infrastructure involves a leap from the traditional infrastructure to modern infrastructure and should be on an equal footing with land, sea, and space infrastructure.

Scholars in China have focused on studying the overall development of the military–civil–commercial integration in the U.S. whereas the research on military–civil–commercial integration in the space infrastructure field is relatively insufficient. This study thoroughly analyzes such integration from the viewpoints of top-level strategies, policies, and regulations, as well as organizational management. Several successful examples are summarized to provide a useful reference for the planning and construction of space infrastructure in China.

2 Status and development trend of space infrastructure in the United States

2.1 Status

During the Cold War (1947–1991), space infrastructure was used to serve military purposes in the U.S. When the military–civilian integration strategy was proposed, the military space-infrastructure was shown to have a wide range of applications in civilian fields such as terrestrial and marine uses, surveying, and environmental protection. Ever since, the space infrastructure is an important resource serving defense and economic purposes. On the premise of ensuring national security, improving the service level of space infrastructure has become a core issue in the U.S.

Over the years, the U.S. has adhered to the principle of military, civilian, and commercial integration. A space infrastructure with large-scale, comprehensive, advanced performance, and complementary military–civilian infrastructure has been established. The U.S. has become the world leader in satellite communications and broadcasting, global positioning system (GPS), and commercial satellite remote-sensing applications. As of 2018, the U.S. has 982 satellites in orbit, accounting for 45% of the global total (Fig.1). It has a satellite communication infrastructure comprising more than 200 satellites. Earth Observation System comprising more than 30 remote-sensing satellites and the new GPS hybrid constellation comprising 32 satellites are to be built to coordinate the requirements of government departments. And the spatial data are shared and distributed through the National Spatial Data Infrastructure Program.

2.2 Development trend

(1) The U.S. highly regards the construction and application of space infrastructure. The development pattern of the space infrastructure is changing from monopoly to diversification.

(2) The core technology in the space infrastructure field is rapidly changing. The integration of space and information technologies has become an important driving force for upgrading traditional industries and transforming human lifestyles.

(3) The fields of the application of space infrastructure are constantly expanding. The rapid updation and large-scale expansion of the applied models of space infrastructure has become the focus; application-led, benefit-first, technology-led, resource sharing, and sustainable development serves as the building guidelines.

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(4) As the observations and services of the global system become the characteristics, international competition and cooperation in the field of space infrastructure have gradually strengthened. Such international competitiveness and cooperation play an important role in safeguarding national space rights, responding to global and common human problems, and resisting natural disasters.

(5) Commercial satellite industrialization is rapidly advancing, resulting in economic benefits. Enterprises have become the main body for satellite manufacturing, application, and innovation, leading to emerging industries and new economic growth points.

(6) Along with an increasingly open policy, the native autonomous system is being increasingly supported, and high-end technology exports and information security are being enhanced.

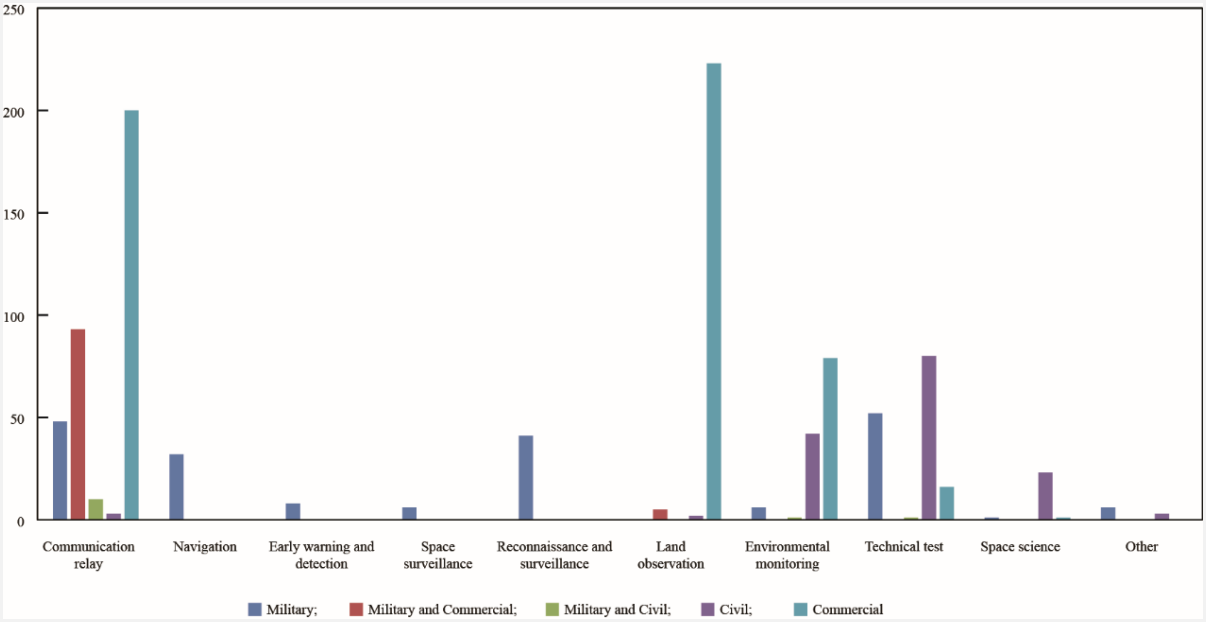

Fig. 1. Statistics of the U.S. satellites in orbit (as of December 2018).

3 Experience related to the military, civil, and commercial integration in U.S. space infrastructure development

3.1 Promulgation of national space policy/strategy guide for the development of military–civilian–commercial integration in space infrastructure

The national space policy is an important reflection of the national strategy (Table 1). The series of policies/strategies adopted by the U.S. clearly define the functions of the Department of Defense (DoD) and the National Aeronautics and Space Administration (NASA), and they form the basic guide for military–civilian–commercial integration in space infrastructure. They have become a policy basis to solve the problems of overlapping management and repeated construction in space infrastructure. For example, it is stipulated that the NASA, U.S. Geological Survey (USGS), and National Oceanic and Atmospheric Administration (NOAA) should eliminate the duplication of civil satellite functions and achieve the unified management of departments for the construction and application of space infrastructure.

If the Department of the Interior provides the remote-sensing information obtained from the National Security Space System for organizations or personnel outside the military, it must be coordinated and communicated between the USGS, the DoD, and the Department of Homeland Security (DHS) [5].

3.2 Regulations and policies emphasizing military, civilian, and commercial integration as the basic idea for U.S. space infrastructure development

The *National Aeronautics and Space Act* stipulates that aerospace development will follow the principle of military, civil, and commercial integration; the scientific research results of military value will be first applied to the military sector; and the military sector will provide marketable research results to the civilian and commercial sectors

to the maximum extent for civil and commercial use.

Particularly, (1) in terms of satellite communication, competition and commercialization form the main direction of communication satellites' development in the U.S. A number of regulations such as the *Communications Satellite Act* and the *Orbit Act* were introduced. (2) In terms of satellite remote sensing, the U.S. focused on military, civilian, and commercial sharing of high-resolution remote-sensing satellite data to be applied for military, civil, and commercial integration. A number of regulations such as the *Land Remote Sensing Commercialization Act* and the *Commercial Remote Sensing Policy* were introduced. (3) In terms of satellite navigation, the U.S. has issued regulations such as the *US Global Positioning System Policy* and *U.S. Space-based Positioning, Navigation, and Timing Policy*, which stipulate that the standard location services be provided free of cost for civilians and businesses to the maximum extent possible for protecting national security and interests. These regulations and policies have played an important role in guiding the military, civil, and commercial integration in U.S. space infrastructure development.

Table 1. Status of national space policy (strategy) in the U.S.

Year	Name	Version	Description
1978	National space policy	First	The basic principles and strategic goals of space activities will be clarified.
1982	National space policy	Second	It has been proposed that the United States (U.S.) will occupy the forefront of the world in the space field.
1988	National space policy	Third	It has been reiterated that the U.S. wants to occupy the forefront in space field; national space activities will be respectively managed according to the military, civil, and commercial sectors.
1989	National space policy	Fourth	It has been proposed that space-based weapons will be deployed as soon as possible.
1996	National space policy	Fifth	The Space Shuttle Project will be continually implemented. The International Space Station Project will be started.
2006	National space policy	Sixth	It has been proposed that the goal of using commercial space capabilities to strengthen the aerospace industrial competitiveness of the U.S.
2010	National space policy	Seventh	It has been required that the U.S. continue to maintain its leading position in space field, the government promotes commercial procurement and services according to international cooperation agreement, and the space infrastructure will be built in three aspects: navigation, communication, and remote sensing.
2018	National space strategy	First	It has been strengthened that the United States' forefront position will be continually maintained in the space field; the U.S. national interests will be put first, strategic cooperation between civil and commercial institutions will be strengthened.

3.3 System compatibility and security as the core issues of military, civil, and commercial integration in U.S. space infrastructure development

The national space policy/strategy has repeatedly proposed that system compatibility and interoperability should be regarded one of the core elements of space infrastructure construction, and the national security system compatibility should be gradually improved in the fields of military operations, military missions, and construction of military services. Furthermore, the effectiveness and efficiency of the national security system should be optimized. Based on the research results of civil and commercial space system construction, the military sectors prioritize system security and compatibility.

To make full use of the U.S. commercial communication satellite resources, the U.S. military has developed a multi-band, intelligent communication terminal: (1) The navy multi-band terminal can replace a variety of (different bands) military satellite communication terminals to achieve an effective reorganization of the existing satellite communication resources. (2) The broadband global satellite program was proposed to enhance the communication capabilities of marine satellites and to develop a universal commercial satellite communication terminal applicable for all types of military ships. (3) A distributed universal ground system was developed to improve the level and ability of signal processing, transmission, and utilization to achieve military, civilian, and commercial information sharing and to build a universal and modular intelligence system.

The U.S. has promoted military, civilian, and commercial integration in space infrastructure development and assigned high importance to system security [5]. To ensure GPS military safety and civilian sustainability, the U.S.

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adopted various measures to improve the anti-jamming performance; these measures include adopting adaptive zeroing antenna technology to improve GPS anti-interference characteristics, adding military code to the GPS system to implement military and civilian signal separation, and enhancing external protection. Simultaneously, anti-jamming measures are applied to commercial satellites. To protect leased commercial communication satellites, the U.S. purchased global satellite interference source geolocation services. Some satellite companies adopted similar methods to secure links and encryption software to improve the security features of satellite terminals. For example, an encryption software is installed at Iridium satellite terminals to restrict its use for only the U.S. military and some users with respect to the use and sharing of data.

3.4 Aerospace management model for military, civilian, and commercial integration and satellite operation management model

In 2017, in response to the increasingly fragmented reality of space activities, the U.S. re-established the National Space Council (Fig. 2) to clearly implement the unified management of military, civilian, and commercial aerospace at the national level. Through various methods such as strategic planning, policies and regulations, and resource sharing, the development of space resources and the maintenance of space security were unified to enhance the role of the space sector in advancing the overall interests of the U.S.

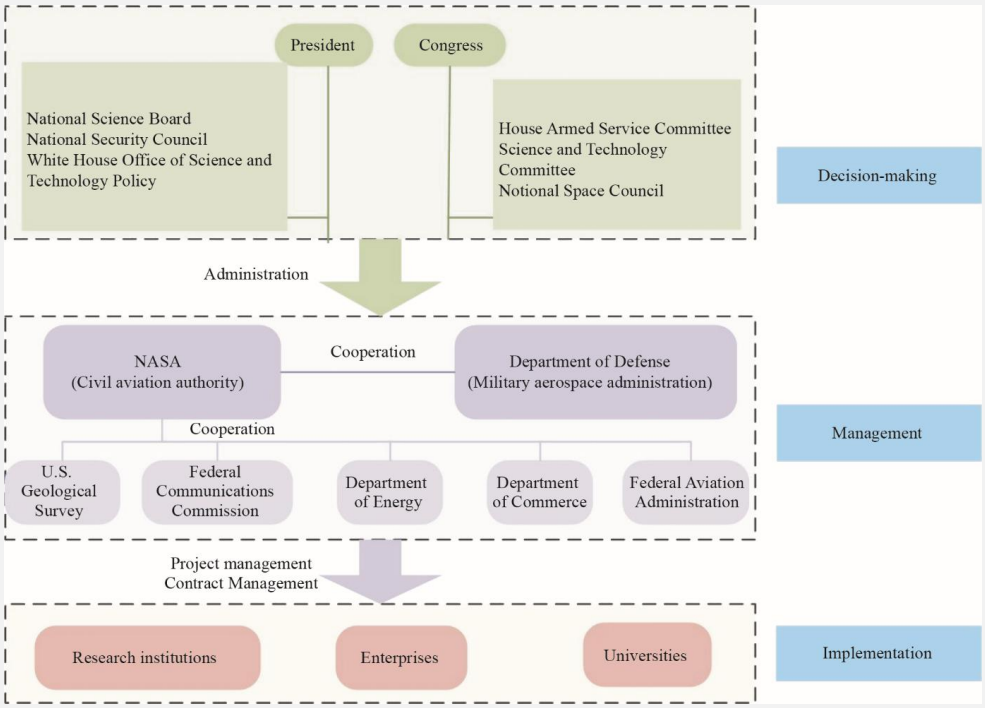

Fig. 2. U.S. aerospace management architecture.

In terms of satellite operation management, the NSTC is the management agency that promotes military, civilian, and commercial integration in accordance with the characteristics and application requirements of satellite systems and the military, civilian, and commercial integrated development model in the U.S. It has been mainly responsible for the collaboration between the DoD, USGS, NOAA, Intelsat, National Space-based PNT Executive Committee, and other departments and companies (Table 2).

3.5 Commercialization as a core model of satellite operation

In terms of communications satellite systems, a number of commercial companies such as Space X and Boeing operate satellite communication systems, provide communication services to the world, and provide military communications services to the military. At present, the U.S. military has supported military building and wartime mission requirements by dispatching multiple military and commercial communications satellite systems; it has developed a procurement plan for commercial satellites to provide resources for wartime military communications. To strengthen the forwarding capability of fixed satellite bandwidth and to provide subscription services for terminal

and bandwidth combination, a procurement plan was formulated for "Global Services for Network Satellite Transmission of Defense Information System."

Table 2. Division of satellite operation management departments (enterprises).

Industry sector/company	Function
NOAA	It has been responsible for the business of meteorological satellites and marine environmental monitoring satellites.
NASA	It has been responsible for the operation and management of scientific experimental satellites.
DoD and military intelligence	It has been responsible for the construction and operation of military communications and reconnaissance satellites.
USGS	It has undertaken the operation of public service earth observation satellites.
Intelsat	It has been responsible for the operation of communication satellites.
National Space-based PNT Executive Committee	It has been responsible for overall management of GPS system, and strengthening department coordination, and industrialization promotion

In terms of remote sensing/reconnaissance satellite systems, the U.S. developed the ClearView and NextView plans to support commercial companies in developing high-resolution imaging satellites and to facilitate the provision of satellite imagery and additional products and services to the government to protect military and civilian requirements.

The U.S. has developed and implemented a coordinated enhanced observation project to support the development and operation of next-generation high-resolution commercial imaging satellites. American companies have managed and operated satellite systems of different commercial resolutions to provide high-resolution observational data for the military [6]. Examples of such systems are QuickBird, WorldView, and EarthEye. The USGS is responsible for operating terrestrial satellites and organizing global data acquisition and data accumulation to provide basic data for the military. NOAA is responsible for operating meteorological marine satellites, performing meteorological marine environmental monitoring, and providing marine atmospheric environmental data to the military. The DoD supports the construction and operation of special-purpose reconnaissance systems such as the defense space reconnaissance program and space-based infrared systems to support the special requirements of military operations.

In terms of navigation satellite systems, the U.S. has formulated and implemented a long-term strategic plan. After the GPS was put into full operation in 2005, several programs such as GPS modernization and GPS III were implemented since 2006. During the initial development of the GPS, the U.S. established a joint GPS program office to resolve disputes among system leaders of armed services. In 1996, an interministerial coordinating executive committee was established to resolve the disputes among military and civilian directors of the Department of Defense and the Department of Transportation. In 2004, the National Space-based PNT Committee Executive was established to further clarify the rights and obligations of various departments and agencies, define the GPS as a national system, and elucidate the relationships between departments. The space segment, operation control segment, and user segment of the GPS achieved remarkable results and have ensured the continuous and stable operation of the system.

4 Insight based on the U.S. space infrastructure development

Military–civilian–commercial integration has its unique characteristics in organizational management, policies, regulations, and system compatibility in the U.S. space infrastructure development. Several successful experiences are summarized to provide a useful reference for the planning and construction of space infrastructure in China.

4.1 Overall planning at the national level to promote military, civilian, and commercial integration in the space infrastructure field in China

At present, China's space infrastructure has been widely applied for economic and defense purposes, and it is in the critical stage of transformation and development. Therefore, the integrated development of military, civilian, and commercial space infrastructure at the national level is proposed.

In accordance with the policy of top-level planning, overall coordination, resource sharing, and technology sharing, the overall planning, design, construction, management, and use of the space infrastructure system will be further promoted. In addition, the space infrastructure construction and application system for military-led, military–civilian–commercial integration will be improved.

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4.2 Specialized agency to coordinate agencies related to space infrastructure construction and application to promote military, civilian, and commercial integration in China

It is recommended to establish a special agency to implement the top-level plan of the national space infrastructure and to achieve coordination between the relevant departments of space infrastructure construction and application, including the Equipment Development Department of the Central Military Commission, the Ministry of Science and Technology, the Ministry of Industry and Information Technology, and the National Development and Reform Commission. The management and coordination mechanism for the construction and application of space infrastructure, including the major issues such as development planning, laws and regulations, policy formulation, funding, engineering construction, and application sharing of space infrastructure, should be improved.

4.3 Strengthening the research and development of satellite application technologies to establish the technological foundation for equipment development

In terms of communication satellite application technology, it is recommended that space- and earth-integrated satellite communication technology integrated with 5G/6G be developed along with space-based information intelligent terminal service technology.

In terms of navigation satellite application technology, a multi-system, coordinated, national integrated navigation system should be constructed. As the core of the national navigation system, the BeiDou satellite navigation system will provide services to meet the most common requirements. In terms of remote-sensing satellite application technology, the application of artificial intelligence technology in the field of ground remote sensing considering future satellite intelligence requirements should be explored.

4.4 Improving the policy and law system to provide policy guarantee to promote the military, civilian, and commercial integration in the space infrastructure field in China

The pace of aerospace legislation should be accelerated. In the field of space infrastructure, a law and regulation system should be formulated to meet the requirements of construction and applications in space infrastructure based on the current status of construction, characteristics of military–civilian–commercial applications, and integrated development. In accordance with the national conditions, institutional policies for technical sharing, resource sharing, and talent sharing should be updated. By strengthening the demand traction, policies for military–civilian integration and satellite remote-sensing data sharing should be formulated. Further, policies for military and civilian standards, confidentiality management, supervision and evaluation, and diversified investment should be formulated.

In addition, the various commercial operation methods adopted by the U.S. military in terms of space infrastructure should be examined to formulate special plans for the leased bandwidth and commercial procurement services of China to further expand the scope of aerospace commercial procurement services to achieve the following: attract domestic private enterprises into the field of space infrastructure; focus on the development of commercial satellites and their ground operation services, information services, and other services; and guide and regulate the compatibility and security of China’s space infrastructure systems.

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