Medium- to Long-Term Strategies in the Field of Space Transportation Systems Formulated by the Institute of Space and Astronautical Science of the Japan Aerospace Exploration Agency under the Inter-University Research Institute System

Abstract

The Space Transportation System Committee of the Institute of Space and Astronautical Science (ISAS) of the Japan Aerospace Exploration Agency (JAXA) has been continuously formulating medium- to long-term strategies in the field of space transportation systems under the Inter-University Research Institute System of ISAS since FY2018. This committee is considering the role of ISAS in cooperation with the organization-wide activities of JAXA to formulate strategies in the field of space transportation systems. Among its previous achievements, the committee assembled a strategic target and scenario for the space transportation system research field at the end of FY2018 and is continuously revising it. Based on the formulated mission scenario, the committee identified three priority areas related to system technologies that must be tackled. These are a "reusable orbit transportation system" that aims for highly frequent mass transportation from Earth to low Earth orbits, a "deep space interorbital transportation system" that aims for a marked improvement in space science and exploration missions in terms of frequency and flexibility, and a "small flying test bed system" for flight demonstrations, which is indispensable in the research and development of space transportation systems. In this paper, the authors summarize the medium- to long-term strategies and their concrete implementation measures over the next two decades.

Keywords: strategy, mission, space transportation system, deep space exploration, small flying test bed, start small

1. Introduction

With the evolution and development of space utilization, the quality of goals and requirements pertaining to space science are expected to advance, provided the number of passengers and amount of cargo to be transported increase significantly. To meet the goals and requirements of space science research fields, we must develop a space transportation network system that can seamlessly connect all fields of space activity.

Accordingly, we identified our mission for strategic research and development (R&D) in the field of space transportation systems (STSs) at the Institute of Space and Astronautical Science (ISAS). This mission envisions that the space science community in the STS field will cooperate with universities, government agencies, and companies for the strategic R&D of key technologies and will continue contributing organizationally to the accomplishment of future space science missions. The mission's first priority is for the space science community in the STS field to contribute to the future evolution and development of space science from their perspective. Moreover, we aim to contribute to the future of human society by applying the obtained results for promoting the space industry, which will be an engine for the expansion of the sphere of human activities.

Furthermore, with regard to our vision for the distant future, our strategic goal may be modified constructively over time. The strategy and tactics for achieving this goal may be repeatedly drafted by an activity platform that is

Abbreviations:
Institute of Space and Astronautical Science (ISAS), Japan Aerospace Exploration Agency (JAXA), research and development (R&D), space transportation system (STS)

organized for the R&D of STS. The chosen medium- and long-term strategies will then be implemented by this platform.

In 2018, the Advisory Committee for Space Engineering, which is the advisory board for the planning, evaluation, and execution of research in the space engineering field, established a new advisory committee called the STS Committee. Since then, this expert committee has been responsible for drafting a strategy to achieve the mission of ISAS in the space transportation field.

The strategic scenario for completing the mission has been framed by considering the background related to space science, which is described as follows: The "Missions of ISAS [1]" state that ISAS will contribute to the development of Japan, which includes space development, by developing an STS that is capable of low-cost, high-frequency missions; moreover, ISAS will develop human resources for the R&D of space science and demonstrate advanced technologies with the Epsilon Launch Vehicle. The "Long-term Vision for Space Transportation System" established by the space policy committee of the Cabinet Office [2] states that the solution to achieve drastic cost reductions in orbital space transportation is to develop space planes that are capable of conducting highly frequent and safe repeated flights, similar to current passenger aircrafts. Furthermore, the "Strategic Scenario over the Next Medium- to Long-term Programs for the research field of Space and Astronautical Science," which was drafted by ISAS/ Japan Aerospace Exploration Agency (JAXA) [3], "the rise of start-up companies in the space transportation field [4]", and "the movement of international space exploration [5]", were also considered when the strategic scenario was drafted.

In February 2020, we added the new concept of fusing transportation with exploration. Currently, the newest version is revision C, which was established in September 2021.

In this paper, we summarize the medium- to long-term strategies and their concrete implementation measures over the next two decades. In addition, part of the information in this paper is reproduced from a conference paper presented at the technical session of IAC 2022 [6] with permission from the International Astronautical Federation.

2. Position of the Institute of Space and Astronautical Science in the space transportation system field

As the medium- to long-term strategies of Japan were still under study in the first half of FY2022, we describe the independent position of ISAS.

2.1 Requirements for research and development in the STS field at ISAS

Based on the vision specified in the national policy of Japan, need for the launch of satellites and spacecrafts, situation pertaining to international space exploration, and next medium- and long-term plans of the ISAS, we defined the requirements for R&D in the STS field at ISAS as follows: First, essential challenges must be overcome when developing a competitive future STS that satisfies the requirements of the "Missions of ISAS" by using high-risk advanced technologies that are too complicated for private companies to tackle. Second, significant success can be achieved with the aid of the Inter-University Research Institute System, which is a unique advantage of ISAS.

2.2 Development of strategic scenarios

To conduct the strategic R&D activities of STSs in the space science field in a sustainable manner, the society must understand the importance, objectives, and accomplishments of STSs. To achieve this, we should attempt to contribute significantly to the development of society, for example, by translating the R&D results related to advanced systems and component technologies into the development of space industries that can contribute to the expansion of the sphere of human activities. Thus, we developed a strategy based on the following deliberations:

2.2.1 Start small

We consider that it is important to “start small” to achieve our target of bringing evolution and development to the field of space science and presenting innovations in society by creating a novel STS. This is because it is important to make modifications and adjustments quickly in the first stage of high-risk developments to produce superior competitive results. In this aspect, ISAS has a history of successful developmental experiences, from the tiny solid “pencil rocket [7]” to the large solid “M-V launch vehicle [8]”, which was capable of deep space exploration missions via small-sized spacecrafts such as the Hayabusa. Fig. 1 presents the pencil rocket with Prof. Itokawa, who is known as the father of rocket development in Japan (left) and the M-V-5 launch vehicle that launched the Hayabusa (right).

2.2.2 Fusion of transportation with exploration

Deep space exploration characterizes the direction of advancement and development of future space transportation in the space science and exploration community. The ISAS has already developed some mission-critical technologies for implementing STSs in deep space through the Hayabusa [9] and Hayabusa2 [10] missions. The ISAS has completed approximately seven years of deep space navigation, rendezvous with and precision touchdown on a noncooperative body (asteroid), and direct atmospheric reentry from the deep space exploration orbit.

3. Mission of ISAS in the STS field

Based on the above-mentioned background and position, we decided to develop medium- to long-term strategies to implement orbit transportation systems, i.e., space planes that are capable of highly frequent and repeated flights, resulting in a significant reduction in transportation costs. Incidentally, we aim to reduce the transportation cost by one to two orders of magnitude from the current level by the 2040s. Additionally, we believe that the concept of an interorbit transportation network system that has a large degree of freedom in its evolution and development will satisfy the requirements for the evolution of STSs with future space science. Therefore, our mission related to strategic R&D in the STS field at ISAS is summarized as follows:

“To build an interorbital transportation network system meeting the future diverse needs of the space science field.”

We plan to conduct related activities by coordinating with communities related to fields other than space science and exploration field achieving our mission. Among the related activities, ISAS can contribute to several areas of advanced technology that will be indispensable for achieving the mission targets, such as highly frequent and repeated flights [11], an air-breathing engine capable of hypersonic flight [12], deep space navigation [13], electric propulsion [14], and atmospheric reentry [15].

The aforementioned technologies, such as the space plane technology that is enhanced in terms of efficiency and function with an air-breathing engine, will contribute considerably to the development of civil space planes for the promotion of the space industry by achieving highly frequent and repeated flights resulting in mass transport.

As specified previously, to acquire the understanding and support of the society, we must attempt to contribute significantly to its development. Therefore, a routine of activities must be established that can translate our superior and advanced R&D results to industries other than those related to the space field.

Fig. 2 shows our strategic target that must be achieved in a step-by-step manner over the next 20 years. We divide our strategic scenario heading toward the target into two phases. The first phase, which has already commenced, has been formulated as a medium-term strategy over a target period of approximately 10 years, considering the future date of the final phase from the present based on the currently achieved technology levels. The second phase has been drawn as a long-term strategy to be completed within approximately 10 years after the end of the preceding phase, based on the promising technology level expected at that time.

Fig. 3 is a conceptual picture of the strategic target from the perspective of the aforementioned "Fusion of Transportation with Exploration" concept. It shows that the interorbital transportation system will contribute to the flexible and frequent exploration of diverse objects in the solar system via a space depot, which will subsequently become a deep space depot.

4. Priority areas of system technologies

Based on the aforementioned conceptual images of the medium- to long-term strategies, we identified the technological challenges that must be overcome and established the development targets and R&D systems.

First, we set the system technology fields to be considered as three pillars. The first pillar is a "reusable STS (space plane)" that aims at highly frequent mass transportation to low Earth orbits as a key technology to develop space exploration to a significant extent. The second pillar is a "deep space and interorbital transportation system" that aims at a marked improvement in the space science and exploration mission in terms of frequency and flexibility. The third pillar is a "small flying test bed system" to conduct flying technology demonstrations, which are indispensable for the R&D of STSs.

Each pillar has multiple development objects. To address the key challenges and complete the mission effectively, cooperation is indispensable, not only with related academia but also with other directories in JAXA and related businesses. Table 1 lists the development objects and their related R&D systems corresponding to each pillar.

Table 1. Development objects and their R&D systems corresponding to each of the three pillars

R&D System	ISAS In-house	Cooperative System	Others
Pillar I.	Soft Aeroshell for Reentry		
Reusable Space			
Transportation	Efficiently Safe Operation		
System		Autonomous Flight Safety	
(Space plane)		Air-breathing Propulsion	
		Atmospheric Reentry	
		Landing Technique	
		Health Management	
		Propellant Management	
		Thermal Protection	
		Light-weight Structure & Material	
			Manned Flight
Pillar II.	Kick Stage		
Deep Space and	Soft Aeroshell for Reentry		
Interorbital			
Transportation		Atmospheric Reentry	
System			
		Landing Technique	
		Advanced Propulsion	
		Health Management	
		Propellant Management	
		Rendezvous Docking	
		On-orbit Assembly	
			Manned Flight
Pillar III.	Efficient and Safe Operation		
Small Flying Test		Autonomous Flight Safety	
Bed System		Air-breathing Propulsion	
	Hybrid Propulsion		
			Manned Flight

5. Roadmap for achieving the mission

We drew a mission roadmap based on the above-mentioned three pillars and their related development objects. Fig. 4 illustrates the mission roadmap that has been drawn up for achieving our mission (strategic target). It also clarifies the respective roles of the three systems in chronological order.

The R&D of reusable STSs, which are the most essential systems in the future STS field, is expected to be initiated based on the experimental study on reusable rocket systems tackled in ISAS so far [16]. By the end of the 2020s, novel reusable sounding rockets equipped with air-breathing engines [17] will be developed, which can undergo scientific research and demonstrations related to advanced spacecrafts and propulsions. Subsequently, in the 2030s, based on the experience and knowledge gained through their developments and operations, we plan to develop a space plane that will be capable of highly frequent mass transportation. The technologies and experiences that would be acquired through the R&D of reusable STSs, including deep space transportation techniques, are expected to significantly contribute to the development of reusable deep space and interorbital transportation systems.

The R&D of deep space and interorbital transportation system will be commenced based on small demonstrators of deep space exploration techniques, such as "DESTINY PLUS [18]", which is under development and will be launched by the Epsilon Launch Vehicle. Additionally, the DESTINY PLUS mission aims to demonstrate small-sized and highly efficient deep space (interplanetary) navigation techniques with a combination of high-performance chemical (solid kick motor) and electrical (ion engines) propulsion systems by the middle of the 2020s. Fig. 5 illustrates the appearance of the DESTINY PLUS spacecraft (upper panel) and its mission profile (lower panel). The results of such recent deep space missions will contribute to the development of future reusable deep space and interorbital transportation systems that are capable of highly frequent and flexible operations.

The small flying test bed systems include solid sounding rockets that are currently being operated, a reusable test rocket vehicle called "RV-X" that is under development, and a "New Sounding Rocket" that is a reusable air-breather equipped with an air-turbo/rocket combined cycle engine named "ATRIUM [19]", which is also under research and will be demonstrated in the late 2020s. Fig. 6 depicts views of the New Sounding Rocket (upper panel) and ATRIUM engine (lower panel). The expected technology demonstration objects are reusable cryogenic combined cycle engines, highly frequent and repeated flight operations of a reusable rocket vehicle, hypersonic engines such as scramjet engines, and thermal protection systems for hypersonic flight and atmospheric reentry, etc. From the 2020s to the middle of the 2030s, we plan to conduct technological demonstration-related research on the advanced STSs using small flying test bed systems and contribute to the development of reusable STSs based on these results.

6. Conclusions

In this paper, we present the medium- and long-term strategies drafted by ISAS/JAXA in the STS research field that must be achieved over the next 20 years to ensure the fusion of STSs with deep space exploration. The core of the strategy is based on developing interorbital transportation network systems, including the space plane system, thereby achieving highly frequent mass transportation, which can contribute to the expansion of the sphere of human activities. To achieve our mission (i.e., our strategic target that has been established based on the discussions by the STS Committee since 2018), we must overcome the current challenges and achieve developments in a wide variety of technological fields. Therefore, we first established the three pillars of the system technology field and subsequently determined the technological challenges that must be overcome, set the development objects, and laid out the direction for the formulation of R&D systems. Current research activities related to STSs must be fused with space explorations; this has been gradually conducted at ISAS on the basis of the strategy briefly described herein. We will strive to systematically implement efforts to overcome the specific technical challenges that are listed in Table 1.

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