

5. Survey Results in “Space”

5.1. Trends in noteworthy domains

5.1.1. Earth observation/global environment

Trends that have emerged in the areas of earth observation and the global environment in the last five or so years will be discussed. In the space development field, the end of Cold War between the United States and the former Soviet Union put an end to the fierce space race between the two superpowers, and marked the beginning of cooperative relationships in space science and technology under a new political framework — a dramatic turnaround which was unthinkable only a few years ago. Compared to other fields, international cooperation and joint research in this field is rapidly gathering momentum. Many countries are putting efforts into fostering a civilian space industry with the aim of reducing military spending and revitalizing the industry as a whole. The active promotion of the space industry in the areas of communication and broadcasting, where communications satellites are used, has begun to have an impact on the development of new social infrastructure over the last few years, spurred on by the popularization of multimedia and the Internet as the pillars of an advanced information society.

In contrast to the contraction experienced by the military industry, growth in the civilian space industry is gradually accelerating, with efforts being made to expand its market by identifying new needs. Communication systems and broadcasting systems exhibit rapid technological progress, boosted by a relaxation in the regulatory control of frequency bands, advances in digitalization technology, and the like. Remote sensing is attracting attention as a new marketing opportunity. Against this backdrop is a relaxation in the restrictions placed on the use of high resolution satellite images, which was until recently severely restricted due to international inspection and military reconnaissance needs.

Along with global environmental problems, the observation of the earth from space has been a focus of attention for some time from a global point of view, amid a surge in international public awareness. Earth observation satellite technology, which came to existence with a Landsat satellite launched in 1972, made steady progress, and is now in the middle of tackling its 90’s challenge — high resolution imagery based on 10-m high resolution sensors pioneered by France’s SPOT satellite system. An expansion in spectral bandwidth, particularly from the visible region to the microwave region, and the practical application of synthetic aperture radar (SAR) is noteworthy. The nature of earth observation is undergoing a transformation from image-based wide-area qualitative survey to quantitative measurement of physical quantities, and this is thought to have had a major impact on the progress made over the last five years. Following the path set by the commercialization of image data obtained via Russian military satellites, commercially-oriented meter-class high-resolution satellites have been already developed, and the technology is moving into a new era.

The launch costs of vehicles that carry satellites into orbit have been falling due to intensified competition involving Europe’s Ariane, China’s Chang Zheng (Long March) and Russian commercial rockets, which have been converted from military rockets. As a result, the number of rocket launch opportunities has increased. To further reduce costs, the development of small rockets is also under way. Meanwhile, the downsizing of observation satellites is making process through improvements in the performance of satellite-borne sensors and R&D on integration etc.

On the heels of these developments, technological forecasts in this field have undergone a significant change. In areas relating to earth observation, sensor development has been taking place in accordance with actual needs, and, as a general trend, forecasted realization times have been brought forward. While it is not surprising to see the bulk of R&D efforts directed towards satisfying research needs close to practical application, the overall social situation also seems to have been playing a part. Of course, in areas where technical difficulties exist with regard to development efforts, forecasting is difficult, even for experts, and this generally leads to long forecasted realization times. Needless to say, forecasting is even harder for non-experts.

In other words, in these areas (earth observation and the global environment), there are many unknown factors in the early stages of research and development, while there are only a limited number of experts, and this tends to work against the formation of a clear long-term outlook. For this reason, the forecast topics, including those concerning related areas, happened to contain technologies which were more like fanciful

dreams and therefore need to be reviewed from the present perspective.

As a general trend over the last five years, research, development and practical application in the areas of earth observation and the global environment have been making rapid progress, with the proportion of technologies put to practical use increasing.

(Toshifumi Sakata)

5.1.2. International space science activities

The study of the evolutionary history of the universe, investigation of the process of planetary formation and elucidation of the environment/conditions for the emergence of life constitute the major goals of space science, and the findings of these research efforts will become common valuable assets for all mankind. Space science transcends the political or economic interests of any nation, and must inevitably be pursued through international efforts. In fact, progress made in the area of space science in recent years has prompted a rise in the size, sophistication and precision of space observation vehicles, giving rise to a situation in which both technical and economic constraints make further progress impossible without international cooperation. Against this background, Japan's X-ray astronomical satellites, solar observation satellites, earth magnetosphere observation satellites, etc. have been made available for use by researchers worldwide, and significant results have been achieved in this regard. As this example shows, Japan's international standing in these areas has been steadily strengthening, giving rise to expectations for a significant international contribution.

With regard to the observation of deep space, hopes are held for the installation of larger observation systems at more favorable locations. In the near future, it is planned to put infrared observation satellites into orbit under the United States' ORIGIN program, Japan's ASTRO-F program, etc., to obtain clues about the birth of galaxies and planetary systems in space. Further down the track, "49: Establishment of a large-scale optical/infrared astronomical observatory at the Lagrange point of the sun and the Earth" is planned. In the area of the observation of cosmic far-infrared radio waves, the "development of an observation system based on a satellite-based interferometer" ("03: Development of a satellite-mounted infrared space interference system with ultra-high space resolution capabilities" and "13: Development of a system to measure cosmic radio waves in the sub-millimeter and sub-sub-millimeter wave band") is envisaged. In the observation of cosmic radio waves using a satellite-based very long baseline interferometer, Japan's "Haruka" satellite, which was launched in February 1997, is playing a pioneering role. Future plans include "39: Set of optical or radio telescopes on the surface of the moon". With such use of the lunar surface in mind, Japan's solar probe program aimed at studying the moon itself is about to begin.

With regard to the study of the solar system /planets, programs such as the following are envisaged: "47: Investigation of Mercury with orbiter" and "48: Exploration of Saturn and other planets beyond it", aimed at probing distant planets; and "44: Long-term observation of the atmosphere of Venus by means of balloons", "45: Analysis of the surface substances of Mars, etc. via an unmanned Mars exploration unit" and "43: Return of samples from other planets", aimed at probing relatively close planets in detail. Of these, Mars probing looks set to weigh heavily in the United States' ORIGIN program, partly due to the recent speculation about the possibility of the past existence of life on the planet. Japan's Mars probe program "PLANET-B" is also in progress. Regarding sample return, Japan's MUSE-C program aimed at collecting samples from asteroids is under way.

Alongside these individual programs, space science research using an international space station will soon become a reality. The space station program relies heavily on international cooperation — to an even greater degree than individual programs — and, for this reason, harbors many political and economic problems. It is therefore hoped that greater efforts will be made by those directly involved in the program, as well as scientists who support it, to ensure that great scientific results are produced by overcoming the above problems.

International space science activities are expected to involve not only the existing players in space development, which are mainly developed countries, but also developing countries in the future. For this reason, it seems necessary for Japan to seek close cooperation with other Asian countries in proceeding with international pursuits in these areas.

(Hajime Inoue)

5.1.3. Space transportation

As space transportation constitutes an essential component of space exploration, various countries have been developing their own technologies. For example, over the last five years, the following launch vehicles have been developed: H-II (1994), J-1 (1996) and M-V (1997) by Japan; ASALV (1994) and PSLV (1997) by India; and Ariane V by the European Space Agency.

On the other hand, in an effort to increase transportation capacities and reduce transportation costs to help implement national projects or further stimulate commercial activities, international cooperation agreements have been drawn up between companies from different countries. Examples include the planned joint modification of the first-stage engine of the Zenit, a Ukrainian rocket, by Russian company NPO Energomash and U.S. company P & W (presently Lockheed Martin Corp.) and its adoption in Atlas 2AR.

In Japan, the development of H-IIA, a low-cost high-reliability launch vehicle, is under way based on the experience of the development of H-II, its predecessor, through system simplification, greater efficiency, the automation of inspection and maintenance work and improved transportation capacity, with the year 2000 targeted for its maiden flight.

Topic 25 has been retained from the previous survey in light of the fact that cost reduction and reliability improvement continue to be priorities for space transportation systems.

In the area of reusable launch vehicles, X-33, Lockheed Martin's experimental demonstration model for the SSTO (Single Stage to Orbit) reusable launch vehicle intended to be the successor to the Space Shuttle, was selected in 1996.

Japanese efforts include the following: the launch of OREX (an orbital reentry experiment vehicle) via H-II in 1994, aimed at obtaining technical data, including basic data on aerodynamic heating during reentry into the atmosphere — as part of building up technological know-how for an unmanned winged reusable launch vehicle; and the launch of HYFLEX, a hypersonic flight experiment vehicle, via J-1 in 1996 to obtain design data for a hypersonic lift-force flight vehicle. In addition, a flight experiment using ALFLEX, an automatic landing flight experiment vehicle, was conducted in 1996 with the aim of obtaining technical data for automatic landing. Incorporating all these achievements, the development of HOPE-X (H-II Orbiting Plan-X), an unmanned reusable launch vehicle experiment model, is under way.

Moreover, with the aim of establishing a rocket-propelled fully-reusable space transportation structure, a study on an SSTO-type space transport vehicle is being undertaken, and research on its component technologies, centered on structural weight reduction technology and reusable rocket engine technology, has begun.

In addition to Topic 21, Topic 20 was incorporated into the questionnaire, in light of the fact that research is under way on an air-breathing propulsion system (the scramjet and air-turbo ramjet) and related technologies with the aim of making a space plane a reality in the future.

In the area of manned space flight, the United States has maintained a manned space program by regularly sending space shuttles into space — approximately seven times a year. Russia has also been launching its Soyuz rockets about twice a year to transport cosmonauts to its Mir space station, and achieved the longest human stay in space for both sexes (437 days for males and 169 days for females) in 1995. Japanese astronauts have also experienced manned space activities, with Dr. Mori, Dr. Mukai and Mr. Wakata participating in space shuttle missions in 1992, 1994 and 1996, respectively.

Currently, the Soyuz and the Space Shuttle are the only manned space flight transportation vehicles. Although this situation will not change for some time to come, Europe is conducting a study on a space station crew transport vehicle called CTV, while the United States (NASA) is engaged in research on a space station crew emergency return vehicle called CRV.

Once the permanent operation of the planned space station becomes a reality, efforts may possibly be directed towards manned and unmanned exploration of the Moon and planets as next-stage projects (topics 37,46 and 51).
(Tsuguhiko Katagi)

5.1.4. Communication and control

(1) Trends in miniature satellites

Generally, as a satellite becomes lighter, the project cost falls, so that low cost is one of the factors that motivate the development of miniature satellites. According to the University of Surrey's definition, satellites are classified as follows: large satellites (1,000 kg and over), small satellites (500-1,000 kg), mini satellites (100-500 kg), micro satellites (10-100 kg) and nano satellites (under 10 kg). While UoSATS, the university's small miniature satellites, are micro satellites normally weighing 10-100 kg, a first study on smaller "nano satellites" was undertaken by the British Ministry of Defense around 1990. It investigated a military communications system involving 52-100 softball-sized 1-kg satellites (called Nanosats) with a service life of 50-300 days without a solar cell (four years with a solar cell according to some reports) deployed in a 400 km-high circular orbit to relay message transmissions. The system envisages the short-term use of UHF telex communication channels for tactical purposes. The unit price was estimated to be £10,000 (\$17,000) subject to volume production, but experts at the University of Surrey were skeptical about the feasibility of a 1-kg satellite. Recently, however AeroAstro, a miniature satellite venture business, designed a 1-kg nano satellite called "Bitsy".

In the latest survey, the "14. Development of satellites weighing 1 kg or less and having communications function" was forecasted to be realized by 2009. Attitudes towards nano satellites vary widely. While some people are very negative about such satellites with communications functions, or are concerned about the increase in space debris, others actively support the idea, identifying it as an area where Japan can make a positive contribution, or believe they would bring space use closer to people's daily lives.

(2) GPS in satellite positioning technology

Regarding satellite positioning technology, the following proposition was included in the latest survey: "15. Realization of a high-accuracy satellite positioning system operated by an international organization". Today, the technology is widely used in Japan in car navigation, geodesy, etc., but it relies almost entirely on the United States' GPS. As a result, some people think that Japan should develop its own system or a system that is complementary to GPS. However, it is not appropriate to pass a judgment on the issue of GPS from only a technical point of view for reasons including the following: it is an extremely well-designed system; it is very expensive and fundamentally a military system, but being a precision satellite positioning system and being a military system are basically two sides of the same coin; and the United States expressed its continued commitment to free access to GPS and intention to push for international standardization in the President's statement issued in March 1996. In March 1997, the Planning and Coordination Subcommittee of the Space Activities Commission prepared a report titled "Approach to Satellite Positioning Technology Development in Japan" in response to the commission's request to deliberate the present state of satellite positioning systems and problems, needs for satellite positioning and future trends, and technological development topics to be tackled by Japan.

In this regard, the report concludes that it is appropriate to start from the following scenario: while basically relying on GPS, Japan should develop the three most fundamental technologies (satellite-borne atomic clock technology, satellite cluster time management technology and high precision satellite orbit determination technology), and conduct R&D on satellite components on the ground in preparation for moving on to satellite development as soon as a concrete plan for the launch of positioning satellites by an international organization emerges, with a minimum number of satellites necessary for demonstration purposes developed. In the United States, the ordering procedure for Block IIF satellites, planned for launch between 2001 and 2016, has been completed. Although the latest survey puts the realization time for the establishment of the above international organization at 2008, this may be a little too optimistic.

(3) Activities relating to info-communications infrastructure with giga-bit satellites as typical example

The United States' National Information Infrastructure (NII) initiative, also known as the Information Highway concept, was announced by President Clinton in September 1993, followed by Vice President Gore's Global Information Infrastructure (GII) proposal in March 1994. Spurred on by these U.S. initiatives, discussions on info-communications infrastructure also became brisk in Japan. In clear realization of the fact that Japan lags behind the United States in info-communications infrastructure technology, the strengthening of R&D activities in this area is also being fairly vigorously debated. In this regard, the view that the Information Highway means optical fiber cable networks was dominant in the United States around the time the NII proposal was made (until late 1994 in Japan). However, apart from optical fiber cables, communications media could include conventional copper cables as well as satellites. In the United States, the fact that the use of satellites makes the implementation of the Information Highway stretching right down to end users easy has been well recognized, and Ka-band satellite communication is booming like LEO satellite communication, with 14 companies having filed applications with the U.S. Federal Communications Commission (FCC). In Japan, too, there has been a renewed recognition of the merit of satellite communication since the tragedy of the Great Hanshin-Awaji Earth Quake. As optical fiber cables are ideal for high-capacity communication between fixed points, it is advantageous to use them for main communication circuits. Satellite communication is particularly suitable for broadcasting, while fiber cables are useless for mobile stations. However, as different sets of bit error rate (BER), communication capacity and delay from those of fiber cables apply, care needs to be taken when designing a circuit.

In Japan, there is a plan to develop a giga-bit experimental satellite for launch around 2002 as the core technology of the info-communications infrastructure. The latest survey included a question regarding "35. Widespread use of gigabit-class global satellite communication systems" as a topic relating to info-communications infrastructure, with the realization time forecasted as 2009. This is probably fairly realistic.

Future tasks in the area of info-communications infrastructure include (1) further utilization of satellite communications for dynamic and flexible system configuration, (2) development of new technologies for high-speed communications satellites, and (3) utilization of the millimeter-wave range and Ka-band, (4) investigation into the development of a 2nd-generation or otherwise special LEO system in Japan, and (5) globalization of and international cooperation over info-communications services.

(Takashi Iida)

5.1.5. New outlook of space environment utilization

Japan's full-fledged space environment utilization began with programs based on the use of NASA's space shuttle missions. In 1979, Japan's first shuttle-based primary material experiment program (FMPT) was adopted, with the public invited to enter proposed experiment themes. Although the FMPT was scheduled to be conducted in 1988, the program was significantly delayed by the explosion of the Challenger and other factors. It was later undertaken in 1992 by Japan's first payload scientist, Dr. Mori, onboard the Endeavor. With subsequent space experiments smoothly carried out, Japan's basic experiment techniques for a manned space lab have by and large been established.

Apart from the FMPT in 1992, space experiment projects implemented using space shuttles over the last five years include: the IML-2 (international microgravity laboratory) carried out by Astronaut Mukai in 1994 and semiconductor experiments conducted in 1995 as part of the D-2 program, a shuttle-based experiment program organized under German initiative, in which the Institute of Space Environment Utilization Research, which is affiliated with the Ministry of International Trade and Industry participated. In addition, space experiments were conducted onboard unmanned experimental satellite SFU, which was launched in 1995 using the National Space Development Agency's H-2 rocket, as a joint project of the Institute of Space Science Research, the National Space Development Agency and the Unmanned Space Experiment System Research and Development Organization. SFU was recovered by the Space Shuttle "Endeavor" during a mission in which Astronaut Wakata took part. These projects mainly took advantage of microgravity conditions in space, and made it possible to identify potential problems which could hinder the effective utilization of a space

station, through actual experiments.

The five-year period starting in 1992 was epoch-making in terms of the utilization of short-time microgravity experiments as well. The operation of two large free-fall experiment facilities owned by the Underground Weightless Experiment Center (Kamisunagawa Town, Hokkaido Pref.) and the Japan Institute of General Weightless Research (Toki City, Gifu Pref.) began, as well as the provision of commercial microgravity experiment services by Diamond Air Service (Nago City, Aichi Pref.) based on the ballistic flight of an aircraft.

Experiment results obtained by NASDA using its TR-1A small rocket are first-class by international standards.

As of 1997, the permanent operation of the International Space Station is scheduled to begin in 2002. Although the launch of the space station's first module was originally scheduled for 1997, the production of the Russian portion of the module has been delayed due to the country's economic problems, giving rise to concerns over possible delays to the entire International Space Station program, of which Russia is a partner.

In 1997, the National Space Development Agency invited the public to enter proposed experiment themes for the initial utilization of the exposed facility of JEM (Japanese Experiment Module), to be built by Japan under the space station program, and screened them. Later in the year, it also plans to invite the public to enter proposed research programs, including those for basic research leading to the future use of the space station, and extend research grants, in order to facilitate the effective utilization of the space station. In recent years, it has begun to be recognized through the experience of short microgravity experiments, which are positioned as preliminary experiments for space experiments in Japan, that much of the research which was in the past considered only possible through the use of a space shuttle or space station can be carried out with relative ease using simpler arrangements and ingenuity. Space environment utilization technology is progressing steadily, and in the unfortunate event that the construction of the International Space Station is delayed, its impact can be minimized by rigorously screening experiment topics to retain only those which absolutely require the use of space, with the rest left to alternative methods.

(Akira Sawaoka)

5.2. Forecast topic framework

In the course of compiling forecast topics, a framework representing the organization of technologies in tabulated matrix form was drawn up for each field, with objectives and technological domains defining the rows and columns of the table, respectively. The framework is designed to present an overall picture of technological development in each field in terms of future prospects, importance, etc. as seen from the present perspective, and is also used as a working framework for future reviews of forecast topics.

Table 5.2-1 Forecast Topic Framework for Space Field

Domain Objective	Low and intermediate orbit	Stationary orbit	Moon and its neighborhood	Planets and deep space
Probing and observation	01		39 40	43 44 45 46 47 48 49
	02 03			
Positioning	04 05 06 07 08 09 10	33 34 35		
	11 12 13 14			
	15			
Environmental applications	16 17 18			
Material and energy-related applications	19	36	41 42	50
Transportation	20 21 22 23 24	37		51
		38		
	25			
Technologies relating to human activities	26 27 28 29			
	30 31 32			

* Figures appearing in the table represent topic numbers.

5.3. Topics with high degree of importance

Degree of importance index scores (Note 1) averaged at 56.2 for topics in the space field as a whole. Topics considered of particular importance to Japan (top 20 topics in terms of degree of importance index score) are listed in the table below. As many as 8 out of the 10 most important topics, including No. 1 and No. 2, were from the low and intermediate orbit domain, although this is partly attributable to the fact that this domain accounted for a large proportion of the forecast topics in the first place. By objective, 5 out of the 10 most important topics related to positioning.

Table 5.3-1 Top 20 Topics in Terms of Degree of Importance Index

Topic	Degree of importance index	Forecasted realization time (year)
25 The cost of rocket thrust space transportation <u>will be reduced</u> to less than 1/10 current levels.	93	2014
09 Realization of precision down to <u>less than a centimeter</u> in measurement of crustal movement using VLBI (very long baseline inter-ferometers), satellite lasers, inverse laser ranging, and synthetic aperture radar to improve accuracy in such as earthquake forecasting.	84	2009
02 <u>Widespread use</u> of a global-scale environmental surveillance network in which environmental changes for the earth as a whole are monitored around the clock in real time, and this information is integrated, systematically analyzed, and distributed around the world.	81	2008

15 <u>Realization</u> of a high-accuracy satellite positioning system operated <u>by an international organization</u> .	81	2008
05 <u>Development</u> of technology for measuring, in real time, the distribution and movement of air pollution via observation from space.	80	2007
35 <u>Widespread use</u> of gigabit-class global satellite communication systems.	78	2009
33 <u>Development</u> in Japan of a satellite broadcast system for each individual region (Kanto, Tokai, Kinki, etc.) based on multibeam technology.	75	2007
20 <u>Development</u> of two-stage-to-orbit, completely re-usable, space transport system.	72	2011
16 Full-scale operation of a space station as a laboratory on the low earth orbit, and <u>realization</u> of next-generation facilities using the space environment for research, development, and trial production of semiconductors, pharmaceuticals, etc.	70	2010
21 <u>Development</u> of a space plane capable of transporting between the earth and space stations in the similar manner as conventional airplanes.	70	2016
29 <u>Removal</u> of large (tens of centimeters and larger) space debris such as pieces of spent satellites, rockets, etc.	68	2015
28 Realization of the identification of relatively large space debris on the order of several millimeters in size (orbiting trash such as shards from satellites and rockets, man-made material ejected into space, etc.), and the <u>development</u> of technology making it possible for space stations and other space structures to avoid collisions with such debris.	68	2014
36 <u>Capability for transmission</u> of electrical power to earth by <u>microwave</u> from solar power generation plants with huge solar cell panels, constructed in space.	65	2020
11 <u>Practical use</u> of global-scale marine and land mapping using satellite-mounted multi-frequency/multi-polarization synthetic aperture radar.	63	2008
32 <u>Development</u> of fail operational space robot with self-diagnostic capabilities and self-restoration capabilities.	62	2014
34 <u>Realization</u> of highly reliable satellite communications and highly accurate earth observation satellites, using clustered geostationary satellites (aggregated geostationary satellites flying in formation).	60	2010
30 <u>Development</u> of life support technology applied to a closed ecosystem, able to self-supply vegetable, grain, animal protein, and other food.	59	2017
10 <u>Practical use</u> of satellite-mounted microwave sensors capable of measuring biomasses within an accuracy of 1Kg/m ² or less. (The dry weight of plants determines the amount of carbon dioxide exhausted, and this is related to global warming. The current status is 1.4Kg/m ² with the shuttle SIR-C.)	58	2008
04 <u>Development</u> of technology to construct of artificial satellites with large-scale antenna (several tens of meters in diameter) at permanent manned space stations in low earth orbit.	58	2008
41 <u>Practical use</u> of substances (Si, O ₂ , ³ He, etc.) which exist on the moon as resources on the moon surface.	58	2026 or later

Note 1: Degree of importance index = (number of “high” responses × 100 + number of “medium” responses × 50 + number of “low” responses × 25 + number of “unnecessary” responses × 0) ÷ total number of degree of importance responses

5.4. Forecasted realization times

Forecasted realization times were distributed as shown in the diagram below.

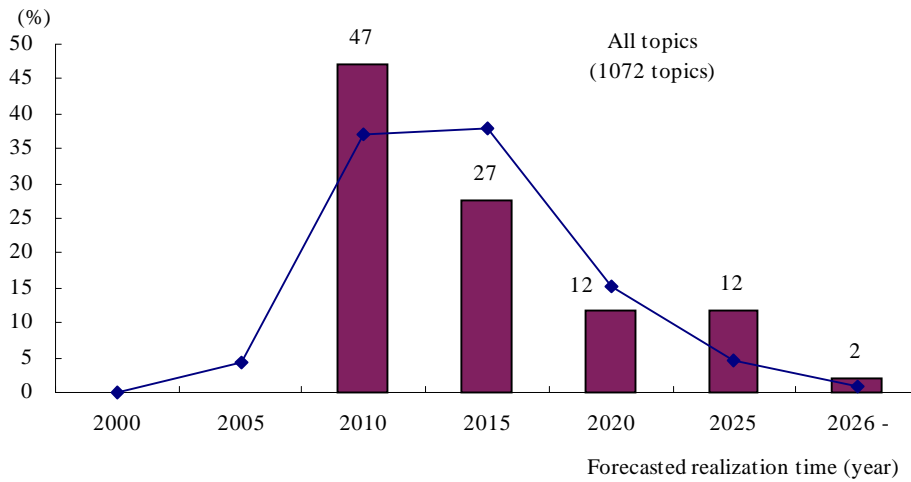


Fig. 5.4-1 Trends in Forecasted Realization Times

About half the forecasted realization times in this field fell between 2006 and 2010, and the rest were distributed after this period, spread over a wide range. A relatively large number of topics had their realization times pushed into the fairly remote future. Compared to the general trend covering all topics, the pattern of the distribution of forecasted realization times displayed was characteristic.

5.5. Current leading countries etc.

Responses to the question concerning current leading countries etc. were as shown in the diagram below. Named by about 90% of respondents, the U.S. ranked No. 1 by an overwhelming margin in the space field as a whole, trailed by Japan, the former Soviet Union/Eastern Europe and the EU in that order.

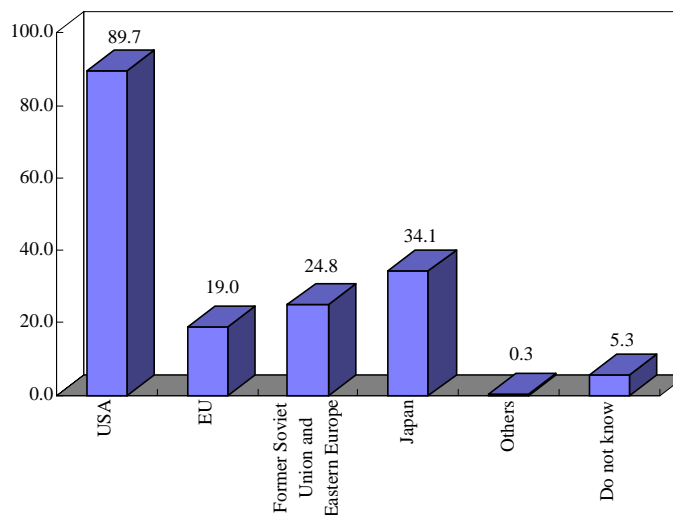


Fig. 5.5-1 Current Leading Countries etc. (%)

5.6. Comparison with the 5th Survey (previous survey)

Of the 51 topics included in the latest survey, 20 (39%) were identical to the previous survey, 9 (18%) were modified, and 22 (43%) were newly introduced. For identical topics, the results of the latest survey were compared with those of the previous survey in terms of degree of importance index scores and forecasted realization times, as shown in the table below.

Degree of importance index scores rose for 2 topics and fell for the remaining 18 topics. 50. Practical use in Japan of isotope batteries for probing deep space saw the greatest drop, down 31 points, with seven other topics experiencing a fall of more than 20 points.

From the 4th to the 5th Survey, forecasted topics were pushed back for all topics. Likewise, from the 5th to the 6th Survey, forecasted realization times were pushed further into the future for all topics, by 2-8 years.

Table 5.6-1 Comparison with 5th Survey for Identical Topics

Topic	Importance index / forecasted realization time	
	6th survey	5th survey
01 <u>Space weather forecasting</u> in order to allow humans to stay and work in space.	48/2007	72/2003
04 <u>Development</u> of technology to construct of artificial satellites with large-scale antenna (several tens of meters in diameter) at permanent manned space stations in low earth orbit.	58/2008	70/2006
06 <u>Practical use</u> of scatterometer to be mounted on artificial satellite for measuring wind velocity on sea in the accuracy <u>less than 1 m/s</u> .	51/2009	59/2004
07 <u>Practical use</u> of a sea color sensor to be mounted on artificial satellites with a spectral resolution of <u>10 nm or less</u> .	56/2008	63/2004
08 <u>Practical use</u> of microwave radiometers to be mounted on satellites, which are designed for measuring water, soil moisture, salt deposit concentration, and ice/snow distribution on land over the entire earth with a space resolution of <u>1 Km or less</u> .	56/2009	72/2005
22 <u>Realization</u> of space tours business by spacecraft in vicinity of earth.	44/2022	42/2016
24 <u>Use</u> of a method in which two satellites or a space station and a satellite are connected with long tethers for variable gravity, power generation, payload acceleration, etc.	41/2013	49/2009
25 The cost of rocket thrust space transportation <u>will be reduced</u> to less than 1/10 current levels.	93/2014	88/2010
26 <u>Development</u> of technologies for removing micro-organisms that lead to uncomfortable factors in space life such as mildew and offensive smells in space stations.	56/2008	73/2004
30 <u>Development</u> of life support technology applied to a closed ecosystem, able to self-supply vegetable, grain, animal protein, and other food.	59/2017	76/2009
31 <u>Development</u> of high-pressure (1 atmosphere), flexible space suit for use outside of a spaceship.	46/2009	76/2006
32 <u>Development</u> of fail operational space robot with self-diagnostic capabilities and self-restoration capabilities.	62/2014	85/2010
36 <u>Capability for transmission</u> of electrical power to earth by <u>microwave</u> from solar power generation plants with huge solar cell panels, constructed in space.	65/2020	67/2018
37 <u>Development</u> of high-performance orbital transfer vehicle to transfer large structures between <u>lower</u> and <u>geostationary orbits</u> .	56/2015	80/2009
38 <u>Development</u> of <u>manned orbital</u> transfer vehicle for trips to and from geostationary orbits and the moon.	49/2021	72/2014
39 <u>Set</u> of optical or radio telescopes on the surface of the moon.	50/2017	59/2012
42 <u>Practical use</u> of nuclear power generating system at lunar bases.	43/2025	54/2018
46 <u>Realization</u> of landing of <u>manned</u> spacecraft on Mars and the return to the Earth.	38/2025	54/2018
50 <u>Practical use in Japan</u> of isotope batteries for probing deep space.	44/2011	75/2004
51 <u>Practical use</u> of space nuclear propulsion systems.	40/2022	64/2016

Note: Up until the 5th Survey, realization meant realization in Japan unless otherwise specified. However, this was changed to mean realization somewhere in the world in the 6th Survey. Therefore, care should be taken when comparing forecasted realization times from the two surveys.

Division	Topic serial No.	Topic	Questionnaire round	Number of respondents	Degree of expertise (%)			Importance (index, %)				Expected effect (%)			Forecasted realization time					Leading countries (%)					Measures the government should adopt (%)					Potential problems (%)								
					High	Medium	Low	Index	High	Medium	Low	Unnecessary	Socioeconomic development	Resolution of global problems	People's needs	Expansion of intellectual resources						USA	EU	Former Soviet Union and Eastern Europe	Japan	Other countries	Do not know	Foster human resources	Promote exchanges among industrial, academic and government sectors and different fields	Upgrade advanced facilities and equipment	Develop a research base	Increase government research funding	Adjust regulations (relax/toughen)	Others	Adverse effect on the natural environment	Adverse effect on safety	Adverse effect on morals, culture or society	Other adverse effects
					2001	2006	2011	2016	2021	2026	Will not be realized (%)	Do not know (%)																										
Low and intermediate orbit	11	Practical use of global-scale marine and land mapping using satellite-mounted multi-frequency/multi-polarization synthetic aperture radar.	1	212	14	31	55	64	37	47	17	0	29	83	29	16		0	8	87	49	12	63	4	7	52	31	24	10	73	2	2	11	9	3	2		
			2	188	12	29	59	63	33	53	14	0	27	87	27	13		0	5	94	52	7	73	3	4	62	28	20	5	80	1	1	11	5	2	1		
			X	23	100	0	0	85	70	30	0	0	30	96	30	17		0	4	96	65	13	91	4	0	78	39	26	0	83	0	0	26	13	0	0		
	12	Development of satellite-mounted Doppler LIDAR capable of measurement of three-dimensional distribution of wind, with a swath width of over 500 km along the satellite flight direction.	1	164	10	32	59	54	22	51	26	1	13	78	32	25		1	9	76	27	4	37	0	16	60	22	23	4	65	2	1	10	12	0	3		
			2	150	10	25	65	51	16	58	25	1	11	85	27	23		1	7	87	30	1	49	0	11	71	19	17	3	75	1	1	10	8	0	2		
			X	15	100	0	0	68	40	53	7	0	33	93	27	20		0	0	93	53	0	93	0	0	67	13	13	0	60	7	0	40	20	0	13		
	13	Development of a system to measure cosmic radio waves in the sub-milli meter and sub-sub-milli meter wave band, using space interferometers.	1	163	9	28	64	48	14	50	34	1	13	18	1	82		0	12	75	25	6	52	1	12	66	20	28	2	66	1	1	9	1	7	2		
			2	153	8	21	71	45	13	42	43	2	7	12	0	90		0	10	84	21	1	59	0	8	75	11	25	2	67	1	1	8	1	2	0		
			X	12	100	0	0	79	67	17	17	0	8	17	0	92		0	0	83	42	0	75	0	0	92	25	25	0	67	0	0	17	0	8	0		
	14	Development of satellites weighing 1 kg or less and having communications function.	1	260	18	36	47	54	28	39	27	6	74	17	35	17		9	10	74	20	3	30	0	13	44	38	18	1	52	9	5	10	15	7	5		
			2	237	17	35	49	57	31	40	23	5	81	9	39	11		7	8	83	20	3	39	0	8	54	41	16	0	62	7	3	7	15	3	3		
			X	40	100	0	0	71	53	33	10	5	85	18	43	23		3	8	88	20	5	35	0	8	55	50	20	0	65	10	3	15	18	8	0		
	15	Realization of a high-accuracy satellite positioning system operated by an international organization.	1	261	12	34	54	76	56	38	6	0	74	28	57	8		3	5	97	22	23	26	0	2	35	32	24	3	62	15	5	3	18	8	3		
			2	232	11	34	56	81	64	33	3	0	84	19	66	4		3	3	97	16	22	29	0	1	41	33	18	1	72	13	3	1	16	3	3		
			X	25	100	0	0	95	92	4	4	0	76	16	68	12		4	0	100	24	48	32	0	0	52	32	20	0	72	8	8	4	20	4	4		
	16	Full-scale operation of a space station as a laboratory on the low earth orbit, and realization of next-generation facilities using the space environment for research, development, and trial production of semiconductors, pharmaceuticals, etc.	1	292	24	37	39	71	49	40	11	1	86	18	29	51		3	2	94	46	59	44	1	1	57	47	26	8	68	5	2	8	7	12	3		
			2	263	22	40	39	70	45	45	9	0	89	11	28	49		3	1	97	44	64	46	1	1	60	46	19	6	76	4	1	8	5	9	2		
			X	57	100	0	0	75	58	27	15	0	89	12	32	53		2	0	98	67	72	60	5	0	56	53	19	5	79	4	2	7	5	7	2		
	17	Realization of a micro gravity research facility capable of an environment of 10 ⁻⁶ G or less for several days.	1	246	23	33	45	58	28	49	21	2	62	10	11	63		7	6	80	37	37	37	0	9	42	29	35	4	61	2	2	5	2	4	2		
			2	225	21	34	45	54	19	60	20	1	64	3	9	69		4	2	91	39	42	46	0	5	49	19	35	2	72	2	1	5	3	3	0		
X			48	100	0	0	67	41	48	9	2	65	4	10	71		0	0	96	44	46	48	2	0	56	25	40	4	79	2	0	10	4	2	0			
18	Realization of large-scale, ultra-high vacuum facility utilizing WAKE (a shielding plate placed perpendicular to the direction of flight on the orbit in order to remove ions and molecules in space).	1	173	18	25	56	44	10	48	36	5	45	5	4	64		5	12	69	14	13	19	0	18	47	25	23	3	53	2	1	8	4	5	5			
		2	164	15	22	63	40	7	44	43	5	39	2	2	78		3	10	76	9	7	18	0	18	57	19	16	2	61	2	0	7	2	3	2			
		X	25	100	0	0	50	17	54	25	4	32	4	0	88		8	0	88	8	16	24	0	8	60	32	24	4	68	4	0	12	4	8	0			
19	Practical use of electricity transmission technology in space using laser beams.	1	240	13	24	63	56	30	42	22	6	55	58	13	14		9	13	71	15	18	29	0	16	50	28	24	2	57	5	1	39	16	3	2			
		2	218	11	24	65	55	27	46	21	6	63	56	9	11		6	10	83	11	17	37	0	10	55	23	22	2	63	4	0	44	18	2	0			
		X	24	100	0	0	61	38	33	29	0	58	54	4	17		8	13	83	8	33	54	0	4	46	21	42	4	71	4	0	25	25	4	0			
20	Development of two-stage-to-orbit, completely re-usable, space transport system.	1	285	31	32	37	70	46	42	11	1	85	23	5	19		4	6	95	21	26	22	0	1	57	26	29	0	75	5	1	17	8	4	4			
		2	259	29	32	38	72	49	42	9	0	88	22	3	17		2	4	95	21	29	25	0	1	64	18	27	0	85	4	0	20	6	2	2			
		X	76	100	0	0	87	75	21	4	0	93	32	7	25		0	4	97	25	33	37	0	0	67	22	41	0	88	4	0	24	3	4	4			

(Note) See page 7 for the interpretation of the graphs.

Division	Topic serial No.	Topic	Questionnaire round	Number of respondents	Degree of expertise (%)			Importance (index, %)				Expected effect (%)			Forecasted realization time						Leading countries (%)					Measures the government should adopt (%)					Potential problems (%)								
					High	Medium	Low	Index	High	Medium	Low	Unnecessary	Socioeconomic development	Resolution of global problems	People's needs	Expansion of intellectual resources	2001 2006 2011 2016 2021 2026						USA	EU	Former Soviet Union and Eastern Europe	Japan	Other countries	Do not know	Foster human resources	Promote exchanges among industrial, academic and government sectors and different fields	Upgrade advanced facilities and equipment	Develop a research base	Increase government research funding	Adjust regulations (relax/toughen)	Others	Adverse effect on the natural environment	Adverse effect on safety	Adverse effect on morals, culture or society	Other adverse effects
					Will not be realized (%)	Do not know (%)	USA	EU	Former Soviet Union and Eastern Europe	Japan	Other countries	Do not know	Foster human resources	Promote exchanges among industrial, academic and government sectors and different fields	Upgrade advanced facilities and equipment	Develop a research base	Increase government research funding	Adjust regulations (relax/toughen)	Others	Adverse effect on the natural environment	Adverse effect on safety	Adverse effect on morals, culture or society	Other adverse effects																
Low and intermediate orbit	21	Development of a space plane capable of transporting between the earth and space stations in the similar manner as conventional airplanes.	1	312	29	29	41	70	46	43	10	1	90	21	11	23		2	5	96	20	24	26	0	2	61	28	30	2	76	4	3	22	9	5	4			
			2	278	28	31	41	70	45	45	9	1	94	17	9	22		1	4	96	19	26	29	0	3	67	21	31	1	84	5	1	29	6	3	2			
			X	79	100	0	0	80	62	33	5	0	91	20	13	30		0	1	99	20	28	41	0	1	70	29	41	1	86	3	0	29	6	5	1			
	22	Realization of space tours business by spacecraft in vicinity of earth.	1	275	19	26	55	46	19	35	38	8	78	6	24	20		4	11	77	9	22	15	0	15	27	34	17	1	43	27	5	15	12	21	3			
			2	254	19	26	56	44	15	36	44	5	80	4	26	19		6	9	83	7	26	16	0	12	27	38	14	0	54	28	4	18	10	17	2			
			X	47	100	0	0	56	28	43	28	2	74	13	34	17		2	2	96	6	32	34	0	4	34	43	36	0	60	28	6	17	9	11	2			
	23	Realization of bases for transporting to the moon and planets in middle or low-level orbiting transport	1	293	21	36	43	54	23	53	21	3	58	27	4	53		3	5	91	16	44	13	0	4	52	25	20	0	68	2	3	7	5	6	3			
			2	263	19	38	43	51	16	58	23	3	59	20	3	62		3	3	94	11	50	11	0	3	53	20	18	0	76	3	2	7	4	4	2			
			X	49	100	0	0	68	42	48	10	0	57	27	0	71		0	0	96	18	55	18	0	2	59	29	29	0	84	2	2	4	0	8	4			
	24	Use of a method in which two satellites or a space station and a satellite are connected with long tethers for variable gravity, power generation, payload acceleration, etc.	1	231	17	30	53	42	11	43	39	7	42	19	4	42		7	13	77	35	8	17	0	9	53	19	21	2	50	0	2	5	3	2	4			
			2	212	14	29	57	41	8	48	40	5	54	12	3	48		3	11	88	40	6	20	0	6	67	13	17	2	62	0	2	5	4	1	2			
			X	30	100	0	0	61	37	40	17	7	50	10	10	63		0	10	83	53	17	47	0	3	53	10	30	0	70	0	7	0	0	3	7			
	25	The cost of rocket thrust space transportation will be reduced to less than 1/10 current levels.	1	300	28	34	37	89	79	19	2	0	93	28	16	20		7	7	85	35	33	27	7	7	43	37	26	1	61	18	3	13	8	5	2			
			2	266	26	36	38	93	86	13	2	0	95	26	13	17		6	6	89	36	32	28	5	4	50	33	23	0	72	14	1	17	6	2	1			
			X	70	100	0	0	96	93	6	1	0	94	34	19	29		3	3	93	37	36	36	9	1	51	41	33	0	73	13	1	13	3	3	1			
	26	Development of technologies for removing micro-organisms that lead to uncomfortable factors in space life such as mildew and offensive smells in space stations.	1	132	19	20	61	55	25	48	25	2	42	9	46	14		1	5	82	15	38	19	0	11	52	41	20	9	49	1	1	6	5	1	3			
			2	127	17	17	67	56	23	56	20	1	44	6	65	8		1	4	86	14	46	19	0	8	66	39	13	6	57	1	0	6	6	0	1			
			X	21	100	0	0	76	57	33	10	0	33	10	71	10		0	0	95	33	71	24	0	0	81	38	10	10	67	0	0	0	10	0	0			
	27	Establishment of a remote medical diagnosis/treatment system for astronauts.	1	143	16	20	64	54	25	43	29	2	36	6	56	15		1	6	88	22	41	18	0	6	53	39	22	11	53	6	0	2	12	10	3			
			2	133	13	17	70	52	20	52	28	1	39	5	68	13		1	5	89	19	49	17	0	5	62	38	19	6	61	3	0	2	11	7	2			
			X	17	100	0	0	75	59	24	18	0	53	0	76	29		0	0	100	53	76	24	0	0	65	59	29	0	76	6	0	0	6	12	0			
	28	Realization of the identification of relatively large space debris on the order of several millimeters in size (orbiting trash such as shards from satellites and rockets, man-made material ejected into space, etc.), and the development of technology making it possible for space stations and other space structures to avoid collisions with such debris.	1	269	16	34	50	66	40	43	15	2	47	28	17	13		7	9	87	19	23	20	0	6	55	20	27	9	64	2	3	7	6	2	3			
			2	239	14	36	51	68	40	50	10	0	62	32	14	10		4	7	93	16	26	23	0	3	65	15	23	5	71	1	2	6	4	2	2			
			X	33	100	0	0	80	67	18	15	0	70	33	21	12		9	6	100	30	33	36	0	0	70	18	27	9	76	3	6	6	0	0	3			
	29	Removal of large (tens of centimeters and larger) space debris such as pieces of spent satellites, rockets, etc.	1	269	16	33	50	64	40	38	20	1	50	38	19	7		9	13	79	16	19	14	0	11	53	22	24	7	61	3	3	10	7	1	3			
			2	241	14	35	51	68	45	40	15	1	60	45	12	4		8	10	87	12	20	12	0	7	63	16	24	4	71	2	2	9	6	0	2			
			X	33	100	0	0	80	70	12	18	0	79	45	24	3		9	9	82	21	27	15	0	3	64	12	18	3	64	9	3	12	6	0	0			
	30	Development of life support technology applied to a closed ecosystem, able to self-supply vegetable, grain, animal protein, and other food.	1	171	15	19	66	62	35	43	19	2	62	49	26	26		3	6	89	18	37	27	0	5	62	38	30	13	61	3	1	9	6	12	4			
			2	156	12	17	72	59	27	58	14	1	69	49	24	22		1	7	95	13	44	34	0	1	72	37	23	8	67	2	1	6	6	10	2			
			X	18	100	0	0	79	61	33	6	0	78	56	44	39		0	0	100	28	50	56	0	0	89	44	28	11	83	0	0	11	6	11	0			

(Note) See page 7 for the interpretation of the graphs.

