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G-TeC Report

A Comparative Study on Space Technology in the World（2015）

Center for Research and Development Strategy
Japan Science and Technology Agency

CONTENTS

Preface

The Center for Research and Development Strategy (CRDS) of the Japan Science and Technology Agency (JST) conducts studies called G-TeC (Global Technology Comparison) in which it investigates and analyzes various countries and regions, focusing on key areas of science and technology, in order to understand Japan's position and contribute to planning of this country's future research and development strategy. This report summarizes the results of an investigation and analysis of space technology, which is the subject of the present G-TeC. This is the third G-TeC study of space technology, following previous studies published in 2011 and 2013.

This study/analysis is based on trends in space development in various countries and regions up to the end of December 2015. It has been two years since the previous study, and there have been considerable changes in space development in each country, with China and India making remarkable progress. In order to investigate and analyze such changes and compare the most recent technologies, a "Committee for Comparative Study on Space Technology in the World" was established at CRDS similar to the previous year. Mr. Shigeru Aoe, former deputy chairman of the Space Activities Commission (SAC), Ministry of Education, Culture, Sports, Science and Technology (MEXT), served as Chairman. Experts from space development organizations, space industries, and research organizations in the several fields which comprise space technology participated as committee members.

This study included a number of changes made to prior investigation methods, with revisions made to the sectors being investigated as well as the relevant evaluation standards and their weighting. Accordingly, a direct comparison of results between the previous evaluation and this evaluation would not be deemed appropriate. The changes made to the evaluation standards were studied in advance by the relevant committee members, with the results raised at a study commission for discussion by the chairperson, deputy chairperson and committee members from other fields. Evaluations were then conducted for each region and country based on the achievements over two years from 2014 to 2015. Note that some technologies are related to defense and as such are made confidential. The study was primarily focused on consumer grade technologies, however to report on the highest level of technology available during the study, the achievements of defense-related technologies was also included. On the other hand, it would also be difficult to say that the development of consumer technologies has been fully disclosed; thus, there may be inaccuracies and other errors in the descriptions herein. We would be most grateful if readers would point out any factual errors, and we will correct those points in a future revision.

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1. General Overview

(1) Global space development trends from 2014 to 2015

In the two years since the previous study, the number of launch and satellite 2014 and 2015 has been summarized for this evaluation. There was a total of 179 rocket launches around the world over these two years, with a total of 472 satellites, including communications broadcasting satellites, earth observation satellites, navigational positioning satellites, astronomical observation satellites and manned spacecraft, placed into orbit by 36 countries and five agencies.

Russia completed 59 launches, with the annual average number of launches dropping below that of 2013. The United States launched rockets 43 times, exceeding the 35 launches by China. Europe launched 12 of its main Ariane 5 launch vehicles from the Guiana Space Centre in South America, while Russia launched seven of its Soyuz launch vehicles and four of the smaller Vega launch vehicles, for a total of 23 launches in the region over the two years. Japan launched one H-IIB launch vehicle and seven H-IIA launch vehicles, for a total of eight launches, just behind India's nine launches. Elsewhere, Israel and Iran both launched one launch vehicle each. During this period, there were a total of eight failures, with the failed launch of a Proton launch vehicle by Russia, and an Antares and Falcon launch vehicle by the United States, and three Russian Soyuz launch vehicles that failed to reach orbit.

Satellite launches were generally successful, with 294 communications broadcasting satellites, earth observation satellites and navigational positioning satellites in the field of space application, eight astronomical observation satellites in fields related to astronomical observation, and 26 manned spacecraft and cargo transport vehicles launched in the field of manned space flight. These included 144 engineering test satellites and AIS satellites, with the annual average number of launches over the period exceeding the 28 launches in 2013.

Cargo transportation to the International Space Station (ISS) suffered from the October 2014 launch failure of American Orbital Sciences (current Orbital ATK) Cygnus cargo spacecraft due to a main engine failure of its Antares launch vehicle, but was followed by a successful launch in December 2015 using an Atlas launch vehicle. The SpaceX cargo spacecraft Dragon suffered a launch failure in June 2015. The Russian cargo spacecraft Progress was damaged in May 2015 during the rocket separation stage, with the mission failing to deliver its cargo. On the other hand, Kounotori 5 launched by Japan in 2015 was hailed as a great success for transporting vital cargo to the International Space Station, including emergency supplies.

The most significant milestone in global space development and utilization over these two years was that of the Falcon 9 reusable launch system manufactured by American company SpaceX. Launched in December 2015, it deployed its payload of 11 satellites and completed its second stage separation before the first stage rocket successfully landed vertically at its Cape Canaveral launch site without any damage. SpaceX is planning more than 20 launches throughout 2016, with a greater range of applications expected for reusable launch systems. The Falcon 9 launch vehicle has the potential making a major impact on global competition for commercial launch programs. Other notable events include the successful test flight of the Russian Angara launch vehicle, and the launch by China of its new generation of light-capacity launch vehicles Long March 6 and Long March 11, all in 2015. China is planning to launch its Long March 5 and Long March 7 launch vehicles from its launch site on Hainan Island from 2016 and on, which is expected to lead to major developments in fields such as manned space flight and lunar exploration.

(2) Results of comprehensive evaluation

The sectors and evaluation standards used for this study have been redefined by revising the results of the previous study based on space activities conducted by each country from 2014 to 2015. Table 1 shows the resulting overall evaluation summary for each sector.

In comparison with the previous results (Reference 1), there is no change in order from the No. 1 position held by the United States, through to the No. 7 position held by Canada. Note that a simple comparison of the resulting numbers should not be used due to the impact of changes in evaluation sectors and standards from the previous study, and the fact that the results are now shown in increments of 0.5.

Table 1 Comparative study of space technology: Summary of evaluation results (2015)

Sector	Max.	US	Europe	Russia	Japan	China	India	Canada
Space transportation systems	30	27	23.5	25.5	18	22	12	0
Space applications	30	28	24.5	15	17	16	9.5	5.5
Space science	20	20	9.5	4	7.5	2	2	0
Manned space activities	20	19	10	17	10.5	11.5	3	4
Total	100	94	67.5	61.5	53	51.5	26.5	9.5
Rank		1	2	3	4	5	6	7

(Maximum possible score: 100, in increments of 0.5)

Reference 1　Results of Previous Study (prepared March 2014)

Sector	Max.	US	Europe	Russia	Japan	China	India	Canada
Space transportation systems	30	27	25	25	17	22	11	0
Space applications	30	29	25	11	19	12	8	5
Space science	20	19	11	8	7	5	3	2
Manned space activities	20	20	9	15	9	10	1	3
Total	100	95	70	59	52	49	23	10
Rank		1	2	3	4	5	6	7

(Maximum possible score: 100, in increments of 1)

Source: “A Comparative Study on Space Technology in the World (2013)”(March 2013)

The evaluation results by country for each sector in this evaluation are described in detail in the following chapters.

2. Space transportation systems

Technology in the sector of space transportation systems (STS) includes launch vehicles and launch complexes, and provides the means of transportation for orbital insertion of a satellite or manned spacecraft which is to perform a mission in that orbit.

The following six elements were identified as the main indexes in the space transportation sector: Number of launches and reliability of launch vehicles, Maximum capability of launch vehicles (payload to GTO), Satellite launch and flight environment, Performance of propulsion systems, Launch operability, and Manned launch technology.

The evaluation results of the space transportation sector are shown in Table 2.

There are no major changes when compared to the previous results (Reference 2).

Table 2 Evaluation results of space transportation systems (2015)

Sector	Max.	US	Europe	Russia	Japan	China	India	Canada
Number of launches and reliability	10	9	10	8	8	9	4	0
Maximum launch vehicle performance	10	9.5	10	6.5	5.5	4	2	0
Satellite launch and flight environment	10	10	10	10	6	6	3	0
Performance of propulsion system	10	9.5	9	7.5	8.5	7.5	8.5	0
Launch operability	10	8	9	10	8	7	6	0
Manned launch Technology	10	8	0	10	0	10	0	0
Total	60	54	47	51.5	36	43.5	23.5	0
Overall evaluation		27	23.5	25.5	18	22	12	0

(Maximum possible score: 60 ⇒ converted to maximum overall evaluation score: 30, in increments of 0.5)

Reference 2 Results of Previous Study (2013)

Sector	Max.	US	Europe	Russia	Japan	China	India	Canada
Number of launches and reliability	10	10	10	8	8	9	4	0
Maximum launch vehicle performance	10	9	10	6	6	4	2	0
Satellite launch and flight environment	10	10	10	10	6	6	3	0
Performance of propulsion system	10	9	9	7	8	7	8	0
Launch operability	10	7	10	9	7	7	4	0
Manned launch Technology	10	8	0	10	0	10	0	0
Total	60	53	49	50	35	43	21	0
Evaluation		27	25	25	18	22	11	0

(Maximum possible points: 60 ⇒ Converted to maximum possible evaluation score: 30)

Source: "G-TeC A Comparative Study on Space Technology in the World" (March 2013)

◎ Summary of space transportation systems in each country

The ranking of countries with the highest number of annual rocket launches in recent years is Russia > US > China > Europe, with Japan and India launching far fewer rockets in comparison. Canada does not have its own space transportation capabilities.

The United States' Delta IV H launch vehicle has the world's highest launch capability, followed by the Long March 5 under development by China at a slightly lower level.

Russia and China are currently the only countries capable of manned launches, with the United States no longer capable of conducting its own manned launches after retiring the space shuttle from service. NASA and companies such as SpaceX are currently developing new systems to be used for manned launches.

◎ Main accomplishments from 2014 to 2015

In 2015, SpaceX conducted four landing tests on a sea barge with the aim of reusing the first-stage launch vessel and engines of the Falcon 9 launch vehicle. Two of these tests failed with the launch vehicle crashing and bursting into flames, one missed the landing site, and one failed during the actual launch. On the fifth test conducted on December 22, the first-stage launch vessel landed successfully at its Cape Canaveral launch site.

◎ Revised sectors and evaluation standards

In the previous study, technology was compared across six elements: number of launches and reliability of launch vehicles, maximum capability of launch vehicles (payload to GTO), satellite launch and flight environment, performance of propulsion systems, launch operability, and manned launch technology. While the same elements have been carried over for this study, the comparison of launch operability was calculated based on the actual timing of launches and shortest interval between launches, in addition to the number of rockets launched annually as used in the previous comparison.

Reusable launch systems have gained attention with the success of SpaceX launches, however have not been included in this evaluation as there is yet no indication of whether these launch systems will be able to achieve the repeated low-cost launches that the company is attempting to achieve.

◎ Future developments (reusable launch systems, heavy-class launch vehicles, small-scale rockets)

SpaceX announced that it currently has more than 50 launches scheduled (manifest), with 26 of those slated to use reusable launch systems in 2016. The Falcon Heavy launch vehicle is also included in these planned launches, which is capable of launching a heavy-class 50-tonne payload into LEO. NASA is also developing a heavy-class SLS with the aim of launching its new manned Orion spacecraft within several years. China is also planning the development of a heavy-class Long March 9 launch vehicle.

Small-scale rockets are being developed with the purpose of launching small satellites, including Vega in Europe, Epsilon by Japan, Long March 6 and Long March 11 by China, and Super Strypi by the United States, which will all compete to improve the efficiency of launch systems.

◎ Emerging country trends

In 2013, Korea ranked No. 11 for launching its own launch vehicles, however no other new players have launched their own launch vehicles since then.

Countries like Brazil, Indonesia and South Africa are likely to join the other countries launching their own launch vehicles in the future.

(1) Number of launch and reliability of launch vehicles

Table 2-1a shows the number of total launches (successful launch + failure), number of failures, and success rate of each country to the end of December 2015. The ranking of the countries with the total number of total launches is Russia > US > Europe > China > Japan > India. The other countries which have capabilities of launching satellites into orbit are Israel (9), Iran (6), and Korea (1).

China is rapidly closing the gap with Europe, and may overtake Europe and become the No. 3 country after the US and Russia within several years.

It should be noted that this table, which summarizes the history of space flight since 1957, is presented here for reference purposes and was not used in the current evaluation.

Table 2-1a Number of launches and launch success rate of countries (1957 to end of Dec. 2015)

Sector	US	Europe	Russia*1	Japan	China	India	Others	World total
Number of Launches	1609	259	3218	97	230	48	16	5477
Number of launch failures	144	13	208	8	13	10	4	340
Launch success rate	91.1	95.0	93.5	91.8	94.3	79.2	75.0	93.8

*1: Results for Russia include launches by Sea Launch.

Note: Number of launch failures includes failure to achieve insertion in the planned orbit due to malfunction of the launch vehicle. Initial failures (i.e., launch failures before the first successful launch of a launch vehicle) are not included.

Source: Prepared by Secretariat based on various materials.

The number of launches and their success rate during the most recent 10 years are considered as the object of this evaluation. As this data covers evaluations on the launch performance of vehicles now in service from around the start of operation, and excludes the performance of older types of vehicles from earlier periods, it is thought to give a good expression of the real capabilities of each country, in terms of launch vehicle reliability, at the present point in time.

In this evaluation, points were assigned as follows:60 or more launches: 5 points, 40 or more launches: 4 points, 20 or more launches: 3 points, 10 or more launches: 2 points, and 1 or more launches: 1 point. The results are shown in Table 2-1b.

Table 2-1b Number of launches and evaluation (Jan. 2006 to end of Dec. 2015)

	US	Europe	Russia	Japan	China	India	Canada
Number of launches	181	63	318	30	136	29	0
Evaluation	5	5	5	3	5	3	0

(Maximum possible score: 5)

Source: Data except the evaluation were prepared by the Secretariat based on various materials.

In evaluating launch vehicle reliability, points were assigned based on the launch success rate as follows: Success rate 98-100%: 5 points, 96-98%: 4 points, 94-96%: 3 points, 90-94%: 2 points, 80-90%: 1 point, and less than 80% or no launch: 0 points. The results are shown in Table 2-1c.

Table 2-1c Evaluation of reliability by launch success rate (Jan. 2006 to end of Dec. 2015)

	US	Europe	Russia	Japan	China	India	Canada
Number of launch failures	5	0	19	0	3	3	0
Launch success rate	97.2%	100%	94.0%	100%	97.8%	89.7%	0
Reliability evaluation	4	5	3	5	4	1	0

(Maximum possible score: 5)

Source: Data except the evaluation were prepared by the Secretariat based on various materials.

The totals of the evaluations of the number of launches and reliability of launch vehicles are as shown in the following Table 2-1d.

Table 2-1d Evaluation of number of launches and reliability of launch vehicles

Sector	US	Europe	Russia	Japan	China	India	Canada
Number of Launches	5	5	5	3	5	3	0
Reliability	4	5	3	5	4	1	0
Evaluation	9	10	8	8	9	4	0

(Maximum possible score: 10)

There were nine launch failures over the past two years. These include three failed launches each of the Russian Soyuz and Proton launch vehicles, one Antares by Orbital of the US, and one each of the Falcon 9 and Super Strypi by SpaceX.

The cause of the Soyuz, Proton and Falcon 9 launch vehicle launch failures were identified and the appropriate modifications completed, and have resumed launches.

(2) Maximum capacity of launch vehicles (payload to GTO)

In evaluating the maximum capability of launch vehicles, it is considered to be appropriate to compare the weight of satellites that can be inserted into a geostationary transfer orbit (GTO). Although the velocity increment necessary to circularize a satellite in geostationary orbit (GSO) differs depending on the latitude of the launch complex, this was also considered in the evaluation because the necessary action is performed on the vehicle side by reignition, etc.

The launch vehicles with the largest capacities among the large operational launch vehicles of each country are as follows.

- US: Delta 4 Heavy, provided by United Launch Alliance (ULA: a joint venture of Boeing and Lockheed Martin)
- Europe: Ariane 5 ECA, provided by Arianespace (prime contractors: Airbus Safran Launchers (ASL: merger between Airbus/Safran))
- Russia: Proton M/Briz M by International Launch Services (ILS)
- Japan: H-II B
- China: Long March 3B/G2
- India: GSLV Mk2

The performance data of the launch vehicles of the respective countries are shown in Table 2-2a.

Table 2-2a Performance Data of Large-scale Practical Launch Vehicles

Country	Launch vehicle	Operator	Payload to GTO	Payload to LEO	Velocity Increment for GSO Insertion ΔV
US	Delta 4 Heavy	ULA	10.1t	28.8t	1500m/s
Europe	Ariane 5 ECA	Arianespace	10.5t	20.0t	1500m/s
Russia	Proton M/Briz M	ILS	6.6t	22.3t	1500m/s
Japan	H-ⅡB	Mitsubishi Heavy Industries	6.0t	16.5t	1500 m/s*1
China	Long March 3B/G2	China Great Wall Industry Corp. (CGWIC)	5.5t	11.5t	1800m/s
India	GSLV Mk2	ISRO	2.5t	5.0t	1800m/s

*1: Capacity in case of upgraded H-II A application

Source: Prepared by the Secretariat based on various materials.

Based on this data, the maximum capacities of the above-mentioned launch vehicles were evaluated by adjusting the maximum payload for GTO by the velocity increment for achieving GSO (1500 m/s: 1, 1800 m/s: 0.75).

Table 2-2b Evaluation of Maximum Capacity of Launch Vehicles

Sector	US	Europe	Russia	Japan	China	India	Canada
GTO capacity x Velocity increment for GSO	10.1	10.5	6.6	6.0	4.125	1.875	—
Evaluation	9.5	10	6.5	5.5	4	2	0

(Maximum possible score: 10, in increments of 0.5)

◎ **Future plans**

Russia, Europe, and China are conducting reviews of the launch capacities of their launch vehicles in line with the trend toward large-scale geostationary satellites (mass of more than 6 tons at launch). Russia is developing the Angara as its next-generation main launch vehicle, and is planning a payload to GTO capacity of 7.5 tons for the Angara A5, and even higher capacities with modified versions of the Angara A5. The Angara A5 successfully completed a test flight in 2014.

In Europe, plans for the Ariane 5 ME were put on hold at the 2014 ministerial-level meeting, and instead began development of the Ariane 6. Planned capacities for the Ariane 6 include GTO 5 tons for the A62, and GTO 10.5 tons for the A64.

China is planning three models of its Long March 5 launch vehicle (CZ-5), with the CZ-5/YZ-2 variant consisting of a large booster and the Yuanzheng-2 upper stage for geostationary orbit deployment, with target launch payloads of 13 tons to GTO and 23 tons to LEO.

Japan began development of the H3 launch vehicle in 2014. The maximum capacity of the H3 launch vehicle is planned to exceed 6.5 tons.

◎ **Small-scale launch vehicles**

The evaluation indexes for small-scale launch vehicles are the payload (satellite) mass that can be inserted into low earth orbit (LEO), sun-synchronous orbit (SSO), and polar orbit. In this study, data for these satellites of this type are limited to those shown in the following Table 2-2c, but are not included in the technical evaluation.

Table 2-2c Performance Data for Small-scale Launch Vehicles

Country	Launch vehicle	Operator	Payload to SSO	Payload to LEO	Remarks
US	Taurus XL	Orbital Sciences	1050kg	1600kg	SSO400km
Europe	Vega	Arianespace	1500kg	2300kg	Polar700km
Russia	Dnepr	ICS Kosmotras	2000kg	3700kg	SSO400km
Japan	Epsilon	JAXA	550kg	1400kg	SSO500km
China	Long March 2C	China Great Wall Industry Corp. (CGWIC)	1200kg	3900kg	SSO400km
	Long March 6	China Great Wall Industry Corp. (CGWIC)	1080kg	—	SSO700km
	Long March 11	China Great Wall Industry Corp. (CGWIC)	350kg	—	SSO700km

Source: Prepared by the Secretariat based on various materials.

The main payloads that are launched by these small launch vehicles are the 500 kg class, as exemplified by Japan's satellite ASNARO. As technology progresses with future earth observation satellites around the world, the direction of development in the "volume zone" of payload mass, i.e., the payload mass generating the largest volume of sales, will be a subject of considerable interest.

(3) Satellite launch and flight environment of launch vehicles

Important considerations related to the satellite loading environment include shock, vibration, acoustics, etc. in the loading environment (payload fairing: PLF) in the nosecone section of the launch vehicle.

In this study, vibration and acoustics were excluded from the evaluation for the following reasons.

First is the vibration environment. As the sine vibration environment conditions are distributed from 0.4G (G: acceleration of gravity = 9.8 m/s2) to 0.9G, even in each frequency band, a comparison of the launch vehicles of the respective countries revealed no large differences.

Regarding acoustics (sound) in the PLF, the actual sound level will vary depending on the fill factor (percentage of PLF volume occupied by a satellite), the structure of the launch complex facilities, etc. For this reason, the acoustic environment is not considered to be an appropriate indicator of technical capabilities and was excluded from the evaluation. As reference values, Table 2-3a shows the overall values (OA) of the acoustic spectrum up to 10 kHz.

Table 2-3a Acoustic environment data (reference)

Country	US	Europe	Russia	Japan	China	India
Launch vehicle	Falcon 9	Ariane 5	Proton M	H-ⅡA	Long March 3B	GSLV
Acoustic OA value (db)	131.4	139.5	141.4	137.5	141.5	Unknown

Source: Prepared by the Secretariat based on various materials.

The shock environment in the PLF can be specified mainly as the maximum shock (G) generated from the time of PLF separation to payload separation, with smaller values indicating a higher level of technical capabilities.

In this evaluation, the values of the shock environment were compared as the object of evaluation. Points were assigned as 1000G or less: 10 points, 2000G or less: 9 points, 4000G or less: 6 points. As no published data were available for India, the evaluation is an estimated value.

The results are shown in Table 2-3b.

Table 2-3b Evaluation of PLF environment of launch vehicles

Country	US	Europe	Russia	Japan	China	India
Launch vehicle	Falcon 9	Ariane 5	Proton M	H-ⅡA	Long March 3B	GSLV
Max. shock (G)	1000	2000	2000	4000	4000	Unknown
Evaluation	10	9	9	6	6	3

(Maximum possible score: 10)

Source: Excluding the evaluation, data were prepared by the Secretariat based on various materials.

(4) Performance of propulsion systems

Types of launch vehicle propulsion systems can be broadly divided into liquid fuel rocket engines (liquid engine) and solid fuel rocket motors (solid motor). The propellants used in liquid engines, in case of bipropellant liquid fuel systems, comprise a combination of a fuel and an oxidizer. In solid motors, powders of the fuel and oxidizer are mixed and solidified, and the propellant is burned in this form.

The performance of the propulsion systems of the main launch vehicles of each country are shown in Table 2-4a.

Table 2-4a Performance of propulsion systems of main launch vehicles

Sector		US	Europe	Russia	Japan	China	India
Vehicle		Delta 4	Ariane 5	Proton M	H-Ⅱ A/B	Long March 3B	GSLV MK-II
1st stage	1st stage main engine Propellant Thrust (kN) Specific impulse (s)	RS-68A LOX/LH_2 3560 414	Vulcain2 LOX/LH_2 1390 434	RD-259 LOX/RP-1 10550 316	LE-7A LOX/LH_2 1098 440	YF-21B N_2O_4/UDMH 2962 260	S139 Solid 4700 266
	Booster Propellant Thrust (kN) Specific impulse (s)	GEM60 Solid 1615 274	MPS Solid 5060 275.4	No booster	SRB-A Solid 2260 283.6	YF-20B N_2O_4/UDMH 732 259	Vikas N_2O_4/UDMH 680 281
Upper	Upper stage engine Propellant Thrust (kN) Specific impulse (s)	RL10B-2 LOX/ LH_2 110 462.4	HM7B LOX/LH_2 64.8 445.5	Briz-M N_2O_4/UDMH 19.62 325.5	LE-5B LOX/LH_2 137 448	YF-75 LOX/LH_2 78 437	CE-7.5 LOX/LH_2 75 454

Note: Thrust unit is N (Newton).

Source: Prepared by Secretariat based on various materials.

The evaluation scores for these propulsion systems were assigned based on the type of fuel, thrust, specific impulse, etc. The systems were evaluated from the following 4 viewpoints:

○ Fuel used:

The maximum possible score of 5 points was given to engines using liquid oxygen/liquid hydrogen

(LOX/LH2) which is a non-polluting propellant, in both the 1st stage and upper stage(s). Engines using the low-pollution propellant LOX/RP-1 were assigned 4 points, and other engines using unsym-dimethylhydrazine (UDMH), which is a toxic substance for humans, were assigned 3 points. Because the 1st stage of the Indian launch vehicle uses a solid propellant, that vehicle was assigned 3 points.

○ 1st stage thrust

Larger values of thrust are advantageous, as gravity drag and atmospheric drag are lower. The total thrust of the main engine and booster was evaluated. Points were assigned as follows: Thrust of 7000kN or more: 5 points, 4000-6999kN: 4 points, and 3999kN or less: 3 point.

○ Upper stage engine: Specific impulse

In the upper stage engine, loss like being considered in the 1st stage main engine decreases,; therefore, priority is given to specific impulse, which is closely related to the velocity increment. Scores were assigned as follows: Specific impulse of 450s or more: 5 points, 400-449s: 4 points, and 399s or less: 3 points.

The evaluation results are shown in Table 2-4b.

Table 2-4b Evaluation of performance of propulsion systems

Sector	Max.	US	Europe	Russia	Japan	China	India	Canada
1st stage main engine: Fuel	5	5	5	3	5	3	3	0
Upper stage engine: Fuel	5	5	5	4	5	5	5	0
1st stage thrust	5	4	4	5	3	3	4	0
Upper stage engine: Specific impulse	5	5	4	3	4	4	5	0
Total	20	19	18	15	17	15	17	0
Evaluation		9.5	9	7.5	8.5	7.5	8.5	0

(Maximum possible score: 10, in increments of 0.5)

The following is reference information concerning propulsion systems currently under development by the respective countries.

The United States is progressing with development of the RS-25 as a first-stage engine for the Space Launch System (SLS) heavy-class launch rocket.

The RS-25 engine is a staged combustion cycle engine which uses a LOX/LH2 propellant and generates 2279kN of thrust and a specific impulse of 452s.

In Europe, the VINCI engine for use as the upper stage of the Ariane 6 rocker is under development. This is an expander cycle engine (high performance closed cycle engine) which uses a LOX/LH2 propellant and generates thrust of 180kN and specific impulse of 465s. Japan's LE-5B engine, with approximately the same thrust, is an expander bleed cycle engine with thrust of 137.2kN and specific impulse of 448s. In comparison with the LE-B5, the performance of the VINCI engine is substantially higher. The lower performance of the LE-B5 is attributed to the increased structural weight of the rocket body due to the engine cycle and larger nozzle expansion ratio; considering this demerit, ultimately, an analysis based on system performance is necessary.

China: Development of a 100t thrust class LOX/kerosene-fueled engine (YF-100) has been completed for the Long March 5. The engine has been installed as the 1st stage engine for the Long March 6 to successfully demonstrate its technical capabilities.

Russia: Development of the RD-191 has been completed as the booster engine of the Angara launch vehicle (stage cluster concept). A derivative type of this engine was also used in Korea’s Naro-1 (KSLV-1). The RD-191 engine is a staged combustion cycle engine (high performance closed cycle engine) which uses a LOX/kerosene propellant and generates thrust of 2085kN and specific impulse of 337s. This is an extremely high pressure engine with a combustion pressure of 263kgf/cm2, which is more than double that of Japan’s LE-7A engine (123kgf/cm2). The Angara A5 successfully completed a test flight in 2014, and is planned to be used as the successor to the Proton.

Japan has announced a development project for the LE-9 engine, aiming to achieve a high reliability and low cost for the country’s H3 launch vehicle. The LE-9 engine utilizes large-scale expander bleed cycle technology (propellant; LOX/LH2, thrust: 1471kN), and is the engine that will be optimized for the system of the H3 launch vehicle. It should be noted that the aim is not necessarily to achieve high performance, as this engine prioritizes the balance of performance, cost, and reliability.

(5) Launch Operability

In order to compare the launch operability of each country, the actual timing of launches and shortest interval between launches were new areas that were investigated, in addition to the time required for mission integration and the number of annual launches from the same complex. The results are shown in Table 2-5a.

Table 2-5a Launch complex operability data

Sector	US	Europe	Russia	Japan	China	India
Mission integration time	18-24 months	10-40 months	12-24 months	18 months	24 months	18 months
Annual launches from same complex	8	7	8	4	7	4
Actual timing of launches	Approximately 70%	Approximately 50%	Approximately 80%	Approximately 80%	Unknown	Unknown
Shortest interval between launches from same complex	13 days	25 days	9 days	25 days	17 days	79 days

Note: Annual launches were evaluated over the period January to December.

No remarkable differences were found in mission integration time, which was generally on the order of 18 to 24 months. For number of launches from the same complex, larger numbers are of course superior.

Naturally a larger number of launches from the same complex is better, and until now Russia and Europe had the highest launch frequency. The United States and China have been increasing their respective launch frequencies in recent years, with 7 to 8 annual launches from the same complex. This is followed by Japan and India with 4 annual launches.

The actual timing of launches and interval between launches was evaluated based on the number of launches over the past 10 years. Evaluations were conducted based on the announcements by launch vehicle operators in each country regarding launch results and delays, as well as they information published on launch results.

The approach used to evaluate the actual timing of launches was to evaluate the probability that a launch vehicle could be launched according to schedule, with the aim of assessing the operations technology of the launch vehicle and ground facilities. When evaluating the launches, delays caused by weather conditions or problems with the satellite, as well as failed launches, were excluded from the evaluation. While information on launch results were available from China and India, information regarding launch delays remain unknown as such information is not published.

Based on the above, launch operability was evaluated with points assigned as follows: mission integration time: 3 points, annual launches from the same complex: 3 points, actual timing of launches: 2 points, and shortest interval between launches from the same complex: 2 points.

Points for mission integration time were assigned based on the shortest possible time as follows: 12 months or less: 3 points, 18 months or less: 2 points, and 24 months or more: 1 point.

Points for the number of annual launches from the same complex were assigned as follows: 6 or more launches annually: 3 points, 4 or more launches annually: 2 points, and 2 or more launches annually: 1 point.

Points for the actual timing of launches were assigned as follows: 80% or more: 2 points, 50 to 80%: 1 point, and 50% or less: 0 points. Note that while the evaluation for the actual timing of launches for China and India remain unknown, they were assigned 1 point.

Points for the shortest interval between launches from the same complex were assigned as follows: 30 days or less: 2 points, and 30 days or more: 1 point.

The results of the evaluation of launch operability based on the above data are shown in Table 2-5b.

Table 2-5b Evaluation of launch operability

Country	Max.	US	Europe	Russia	Japan	China	India	Canada
Mission integration time	3	2	3	3	2	1	2	0
Annual launches from same complex	3	3	3	3	2	3	2	0
Actual timing of launches	2	1	1	2	2	1	1	0
Launch interval	2	2	2	2	2	2	1	0
Total	10	8	9	10	8	7	6	0

(Maximum possible score: 10)

(6) Manned launch technology

At present, only Russia and China are capable of manned transportation on a regular basis. Regarding launch frequency, transportation to the ISS (International Space Station) and China’s Tiangong is performed 4 times/year with Russia’s Soyuz and around once every 2 years with China’s Shenzhou.

Since 2009, Russia has transported crews of 3 persons/launch 4 times/year. China's launch vehicle carries a maximum crew of 3 persons and docks with the Tiangong 1.

Because the United States already possesses manned launch technology, an evaluation was conducted on the basis of its past performance. In the US, the National Aeronautics and Space Administration (NASA) is now developing a capsule-type Multi-Purpose Crew Vehicle (MPCV) for exploration of Mars, and the private sector is developing a Commercial Orbital Transportation System (COTS). The Falcon 9 launch vehicle, which was successfully developed by SpaceX, is not limited to transportation of materials to the ISS, but is also very likely to extend to manned launches.

Full points were given to Russia and China, which possess manned transportation capabilities at the present point in time. Although the United States currently does not operate manned launch vehicles, 8 points were assigned to the US considering its past performance. Europe, Japan, and India do not have manned launch capabilities at present, and were thus assigned 0 points. The evaluation results are shown in Table 2-6.

Table 2-6 Evaluation of manned launch technology

	US	Europe	Russia	Japan	China	India	Canada
Evaluation	8	0	10	0	10	0	0

(Maximum possible score: 10)

Source: Excluding the evaluation, data were prepared by the Secretariat based on various materials.

(7) Summary of space transportation systems sector

Based on the analysis of the space transportation capabilities of each country outlined above, a relative evaluation of the levels of the 7 main countries/regions in the space transportation systems sector was conducted. Out of a maximum possible score of 100 for the comprehensive evaluation of all sectors, the space transportation systems sector is assigned 30 points. Since the maximum possible score for the six items in this sector is 60 points, points for use in the comprehensive evaluation were calculated by multiplying the total scores in this sector by a conversion factor of 30/60.

Canada received 0 points because it is not developing a space transportation system.

The results of the total evaluation of the space transportation systems sector are shown in Table 2-7(same as Table 2 on P8).

Table 2-7 Total evaluation of space transportation systems sector

Sector	Max.	US	Europe	Russia	Japan	China	India	Canada
Number of launches and reliability	10	9	10	8	8	9	4	0
Maximum launch vehicle performance	10	9.5	10	6.5	5.5	4	2	0
Satellite launch and flight environment	10	10	9	9	6	6	3	0
Performance of propulsion system	10	9.5	9	7.5	8.5	7.5	8.5	0
Launch operability	10	8	9	10	8	7	6	0
Manned launch technology	10	8	0	10	0	10	0	0
Total	60	54	47	51	36	43.5	23.5	0
Overall evaluation		27	23.5	25.5	18	22	12	0

(Maximum possible score: 60 ⇒ converted to maximum overall evaluation score: 30, in increments of 0.5)

3. Space applications

Technology in the space applications sector was evaluated in the 4 fields of satellite bus, satellite communication/broadcasting, Earth observation, and navigation and positioning. Each of these 4 fields play a vital role for space development and utilization by each country. When space missions are examined, it is not only the individual technologies that are being used, but there are also new missions being created through the combination of 2 or 3 of these fields. For example, satellites that gather data for the Automatic Identification System (AIS), which can be considered a type of communications satellite, can be combined with earth observation satellites to identify ships that are not broadcasting AIS data and thus assist with the detection of unidentified ships. AIS data also includes positional information acquired from navigational positioning satellites. In another example where satellites contribute to greater convenience, combining earth observation satellites with navigational positioning satellites can provides tourism and other guidance data that utilizes the Geographic Information System (GIS). The combination of communications satellites and navigational positioning satellites is anticipated to deliver more accurate positional information than in the past, which can assist with accidents involving aircraft or ships.

Satellite buses consist of a combination of common equipment required for these types of satellites. China uses similar types of satellite buses for navigational positioning satellites and lunar orbiters. Even Japan uses the same satellite bus developed by the private sector for its communications broadcasting satellites and navigational positioning satellites.

There are many cases in the space applications sector where each of these fields are interconnected like in the examples above, however this study has evaluated each of these fields using a separate scale.

The results of this total evaluation of the space applications sector are shown in Table 3.

Table 3 Total evaluation of the space applications sector (2015)

Sector	Max.	US	Europe	Russia	Japan	China	India	Canada
Satellite bus technology	10	10	9.5	5.5	7	5	3.5	1
Satellite broadcasting	10	9	8.5	3	5	3.5	2	3
Earth observation	10	8	8.5	4	6	5.5	4	3
Positioning	10	10	6	7.5	4.5	7	3	0.5
Total	40	37	32	20	22.5	21	12.5	7.5
Overall evaluation		28	24.5	15	17	16	8.5	5.5

(Maximum possible score: 40 ⇒ converted to maximum overall evaluation score: 30, in increments of 0.5)

The results of the previous evaluation are shown in Reference 3.

Reference 3 Total evaluation of the space applications sector (2013)

Sector	US	Europe	Russia	Japan	China	India	Canada
Satellite bus technology	10	10	5	8	5	4	1
Satellite broadcasting	9	8	2	6	3	2	3
Earth observation	9	9	3	6	4	4	3
Positioning	10	6	5	5	4	1	0
Total	38	33	15	25	16	11	7
Overall evaluation	29	25	11	19	12	8	5

(Maximum possible score: 40 ⇒ converted to maximum overall evaluation score: 30, in increments of 1)

The results of an evaluation of the technologies of each field are shown as follows.

(1) Satellite bus technology

Various types of mission equipment are loaded in satellites, however all satellites must have certain basic equipment. The combination of this common equipment is called a “satellite bus.” This equipment includes the body system, electrical system, attitude control system, guidance control system, propulsion system, and TTC (Telemetry, Tracking and Command).

Among satellite buses, a bus that can be used in common, independent of the mission purpose, is called a "standard bus." Special buses and unique buses have a characteristic shape and features in each satellite, corresponding to the purpose of the mission, and are frequently one-of-a-kind products. In contrast, standard buses can be considered mass-production type buses.

(a) Standard bus technology for geostationary satellites

While larger, higher capacity satellites are continuing throughout the communications broadcasting field, there are a number of medium-scale satellites available now where some or all of the conventional chemical propulsion system has been replaced with an electrical propulsion system.

In the United States, Boeing developed the all-electric propulsion satellites ABS-3A and Eutelsat 115WB. The satellites took 6 months using their electric propulsion systems to reach their designated orbital position and begin communications services, demonstrating the orbital capabilities of all-electric propulsion satellites. In addition to the SES-15, Boeing is said to be currently manufacturing several other all-electric propulsion satellites. In Europe, Airbus has received orders for 3 all-electric propulsion satellites (SES-12, Eutelsat 172B and SES-14).

The standard buses for geostationary satellites were compared as the representative type of standard bus. While the same evaluation standards uses almost all items from the previous study, the accumulated orbital operation history and other factors were also evaluated instead of just the number of annual launches. The general evaluation method and assigned points for each item were also revised.

As in previous studies, there is no change in the fact that US satellite manufacturers continue to hold a dominant position. Russia did overtake Europe with the number of launch vehicles launched, however Europe is likely to make a comeback with the number of launch vehicles ordered.

Europe successfully launched the first Alphabus/Alphasat next-generation communications satellite in 2013. Development of this system was carried out as ARTES-8 in the ARTES (Advanced Research in Telecommunications Systems) program run by the European Space Agency (ESA). The Alphasat I-XL satellite was launched as Inmarsat IV-A F4. Yet Airbus and Thales Alenia Space continue to use their respective Eurostar and Spacebus type buses, and Alphabus is not widely used at this point in time.

China is beginning to increase its track record with launches of its independently-developed Dongfang Hong 4 satellite bus, however there has only been one order from 2014 to 2015.

Japan is also increasing its records of orders, with two orders from Qatar for Mitsubishi Electric’s DS-2000 for two communications satellites, among others.

In Russia, the first privately established satellite manufacturer, Dauria, received orders for two satellites from India.

India has limited its satellite production to domestic purposes.

In Canada, MDA acquired Space Systems/Loral (SSL) in 2012 to become its parent company, however still has not yet developed anything that can be considered a domestic satellite bus system.

The names of the main large-scale satellite buses of each country, their main specifications, record of orders received in 2014 and 2015, and orbital operation history are shown in Table 3-1a.

Table 3-1a Representative standard buses for geostationary satellites of each country

Country	Company	Bus	Weight at Launch	Max. Electric Power	Design Life (years)	Orders Received	Orbital Operation History*
US	Lockheed Martin (LM)	A2100A	3-6t	18kW	15	2	450 years or more
	Boeing	BSS702	5-6t	17kW	15	4	No published values
	Space Systems/ Loral (SSL)	LS1300	6-7t	25kW	15	14	1900 years or more
	Orbital Sciences Corp. (OSC)	Geostar-1/-2	2-4t	5kW	15	5	No published values
Europe	Airbus	Eurostar-3000	5-6t	18kW	15	8	500 years or more
	Thales Alenia Space (TAS)	Spacebus-4000	5-6t	15kW	15	8	500 years or more
Russia	ISS Reshetnev	Ekspress-2000	3-4t	N/A	15	1	No published values
Japan	Mitsubishi Electric	DS-2000	3-5t	14kW	15	1	50 years or more
China	China Academy of Science and Technology(CAST)	Dongfang Hong 4	5t	18kW	15	1	No published values
India	Indian Space Research Organi-zation (ISRO)	I-3000, I-4000	2-3t	N/A	10	2	No published values

Note: For Russia, the object satellite bus in this evaluation was changed to the most recent type.

* Total years elapsed of all satellites launched by this satellite bus

Source: Prepared by Secretariat based on various materials.

Table 3-1b shows the results of an evaluation based on a total consideration of the launch weight, maximum power, design life, and number of orders received for the representative satellite buses shown in Table 3-1a.

Table 3-1b Evaluation of standard buses for geostationary satellites

Evaluation	Max.	US	Europe	Russia	Japan	China	India	Canada
Weight	2	2	2	1	1	1	1	0
Power	2	2	1	1	1	1	1	0
Life	2	2	2	2	2	2	1	0
Orders	2	2	2	1	1	1	1	0
History	2	2	2	1	1	0	0	0
Evaluation	10	10	9	6	6	5	4	0

(Maximum possible score: 10)

(b) Lineup of satellite buses

Lineups of satellite buses were evaluated from the viewpoint of diversity of satellite buses, including standard buses, special buses, unique buses, etc.

Medium- or small-scale satellite buses of each country are used with circular orbit-type earth observation satellites, navigational positioning satellites, and other satellites. There is an increasing range of satellite buses available by each country, including Japan, for small-scale and ultra-small-scale satellites, indicating the need for standard buses to suit each scale of satellite.

Notable examples include the United States with Orbital ATK's Star bus, and SNC's SN100S bus used in the Orbcomm satellite, as well as Europe with the ELiTeBus bus made by TAS and used in the O3b satellite.

In Japan, ASNARO-1 using the NEXTAR bus made by NEC was launched in 2014, while GCOM-C1 that will be launched in 2016 uses an even larger GCOM bus. The Hayabusa 2 launched in 2015 adopts the same bus used in the Hayabusa. In 2014 Mitsubishi Electric launched the ALOS-2, which used a DS-1000 bus smaller than its DS-2000 bus, and in 2017 is planning to launch the GOSAT-2 using the same DS-1000 bus.

Buses for the Beidou 3 satellite system (medium Earth orbit and inclined geosynchronous orbit), which does not use an apogee engine, has started being used as a new variation of China's circular orbit satellite bus.

India is using an improved version of its existing I-1000 (I-1K) bus for its IRNSS positioning satellites.

Table 3-1c shows the results of an evaluation of technical capabilities, considering the performance and actual results by type of satellite in the lineups of each country.

Table 3-1c Evaluation of lineups of satellite buses

Sector	Max.	US	Europe	Russia	Japan	China	India	Canada
Geostationary satellite bus	4	4	4	3	3	3	2	0
Circular orbit satellite bus	3	3	3	3	3	1	1	1
Special bus	3	3	3	2	2	2	1	0
Evaluation	10	10	10	8	8	6	4	1

(Maximum possible score: 10)

(c) Satellite parts, element technologies, components, etc.

In evaluating the technological competitiveness of satellite buses, technical capabilities related to satellite-mounted parts, element technologies, components, etc. are also important.

The United States continues to keep its dominant position for parts on satellites, however Europe is strengthening its competitiveness in order to secure its independence and avoid depending on a single supply source. This trend is exemplified by ITAR-free satellites, which are not subject to US export regulations. China has also established a scheme for independent production. On the other hand, in Japan, domestic space-parts manufacturers are tending to withdraw from this business, and as a result, Japan's competitiveness shows a decreasing tendency.

Element technologies and components that are exported from each country exhibit a high level of international competitiveness. Japan has numerous items with a high level of international competitiveness, such as satellite communications equipment, solar cell panels, and lithium-ion batteries. MDA of Canada has outstanding technical capabilities with robot arms, which is one element technology.

In the case of individual components and parts such as integrated circuits, solar cell panels and batteries, etc., which are used in every satellite bus, products from various countries are used in an intermixed manner.

The results of a technical evaluation of these satellite parts, element technologies, and components, and an evaluation of the respective shares of the countries in the international market are shown in Table 3-1d.

Table 3-1d Evaluation of satellite parts, element technologies, components, and international market share

Sector	Max.	US	Europe	Russia	Japan	China	India	Canada
Satellite parts	2	2	2	1	1	1	0	0
Element technologies	3	3	3	1	2	1	1	2
Components	3	3	3	1	2	1	1	0
International market share	2	2	2	0	1	0	0	0
Evaluation	10	10	10	3	6	3	2	2

(Maximum possible score: 10)

(d) Reliability of satellite buses

The insurance rating assessments of satellite insurance companies were used as an index for evaluating the reliability of satellite buses. Space insurance is broadly divided into four types, pre-launch insurance, launch insurance, third-party liability insurance, and in-orbit insurance.

Of these types, in-orbit insurance covers physical damage of the satellite while in orbit (malfunction of onboard equipment, loss of satellite functions, shortening of satellite life, etc.) and is applied through the operational life of the satellite. In this study, the reliability of various buses was evaluated from the viewpoint of the insurance underwriter, focusing on in-orbit insurance.

The underwriter analyzes the design specifications of the satellite and the health status of the satellite in orbit, and calculates the insurance rate considering conditions in the space insurance market. Therefore, in this study, the reliability of the main buses was evaluated based on insurance rates, with the cooperation of Mitsui Sumitomo Insurance Co., which is one insurance underwriter. The results are shown in Table 3-1e.

However, it should be noted that the insurance rates of space buses fluctuate greatly depending on conditions in the space insurance market.

Table 3-1e Evaluation of reliability of main satellite buses based on in-orbit insurance rates

	Europe		US				China	Japan
Satellite maker	Thales	Airbus (formerly Astrium)	Boeing	LMCSS	Orbital ATK	SSL	CAST	Mitsubishi Electric
Representative buses	Spacebus -3000, -4000	Eurostar-2000, -3000	BSS-602, -702	A2100	Star-2	LS-1300	Dongfang Hong 4	DS-2000
Evaluation	4	5	5	5	4	5	3	5

(Maximum possible score: 5)

Based on these data, there was no difference in evaluations among Europe, the US, and Japan, and all three countries were assigned 5 points. China received 3 points. Although no data were available of Russia and India, both are thought to have significantly lower reliability than China, and therefore were assigned 2 points. Canada was scored 0, as that country does not possess satellite bus technology. The results are shown in Table 3-1f.

Table 3-1f Evaluation of reliability of satellite buses

	Max.	US	Europe	Russia	Japan	China	India	Canada
Evaluation	5	5	5	2	5	3	2	0

(Maximum possible score: 5)

(e) Summary of satellite bus technology

Based on the individual evaluations presented above, the results of a total evaluation of the level of satellite bus technology are shown in Table 3-1g.

Table 3-1g Total evaluation of satellite bus technology

Sector	Max.	US	Europe	Russia	Japan	China	India	Canada
Standard bus technology	10	10	9	6	6	5	4	0
Lineup	10	10	10	8	8	6	4	1
Parts, etc.	10	10	10	3	6	3	2	2
Reliability	5	5	5	2	5	3	2	0
Total	35	35	34	19	25	17	12	3
Overall Evaluation	10	10	9.5	5.5	7	5	3.5	1

(Maximum possible score: 35 ⇒ converted to maximum overall evaluation score: 10, in increments of 0.5)

(2) Satellite communication/broadcasting

(a) Development of satellite communication/broadcasting technology

High-throughput satellites (HTS) have received considerable interest with satellite communication/broadcasting, and around 50 satellites have already been launched internationally. HTS are high-speed, high-capacity satellites that operate in the Ka band using spot beams with frequency re-use to achieve at least double the throughput (with some that are tens of times faster) as conventional satellites over the same bandwidth.

Overseas, HTS services have started providing a throughput of more than 100 Gbps, which drastically reduces the unit cost of communications services. While Direct to Home (DTH) satellites are considered to remain in use mainly for services such as regions where there is still significant demand for television broadcasting, a growing shift to HTS within the communications satellite market is clearly evident.

Viasat-1 launched in 2011 was the world's fastest (approximately 150 Mbps) HTS to date, however the Echostar-19 (Jupiter-2) that is planned to be launched by SSL of America in 2016 is expected to provide communications capacity in excess of Viasat-1.

All-electric propulsion satellites, where conventional chemical propulsion systems are replaced with electrical propulsion systems, can drastically reduce the weight of satellite buses, and become even more beneficial when combined with HTS that need a greater weight capacity for their communication payload. The ABS-3A and Eutelsat 115WB satellites launched by Boeing of America in March 2015 reached their designated orbital position from September to October last year and began communications services, demonstrating the orbital capabilities of all-electric propulsion satellites.

To ensure the highest level of performance for HTS operations, a flexible payload function is required that allows adaptable changes to the communication configuration, including beam patterns or inter-beam connectivity.

In the United States, satellite manufacturing companies such as Boeing are actively applying the advanced technologies developed for defense satellites to civilian communications broadcasting satellites as part of continual technical innovation.

Satellites developed in Japan for satellite communication technology include the engineering test satellite Kiku 8 (ETS-VIII) launched in 2006, and the ultra-high speed internet relay satellite Kizuna (WINDS) launched in 2008. The engineering test satellite Kiku 9 (ETS-VX) is planned to be launched in 2021.

Europe is engaged in technical development in the satellite communications field in the ARTES (Advanced Relay and TEchnology MISsion) program, in which the European Space Agency (ESA) is developing advanced communications technologies; examples include the Alphabus (ARTES-8), the small-scale geostationary communication/broadcasting satellite bus (ARTES-11), and the NEOSAT bus (ARTES-14).

In China, Laosat-1 was launched in 2015 using the Dongfang Hong 4 bus for the first satellite operated by Laos.

Russia, India, and Canada have not developed noteworthy new technologies, but are developing and manufacturing independent communication/broadcasting satellites by combining globally-established element technologies.

Table 3-2a shows the results of a relative evaluation of the development of the communication/broadcasting technologies outlined above.

Table 3-2a Evaluation of technical development in satellite communications broadcasting

Sector	Max.	US	Europe	Russia	Japan	China	India	Canada
Large capacity satellite communication	2	2	2	0	1	0	0	0
Mobile communications	2	2	2	0	0	0	0	0
Reconfigurability	2	2	1	0	0	0	0	0
Large capacity, high speed broadcasting	1	1	1	0	1	0	0	0
Confidentiality/survivability	1	1	1	0	1	0	0	0
Data relay	1	1	1	1	1	1	0	0
Inter-satellite optical communications	1	1	1	0	1	0	0	0
Evaluation	10	10	9	1	5	1	0	0

(Maximum possible score: 10)

(b) Missions of satellite communication/broadcasting

Until now, television broadcasting had been the largest user of missions of satellite communication/broadcasting.

India is the most advanced country in the field of remote learning, and has realized high quality education throughout the country by utilizing satellite communications in elementary school classes. India is also providing know-how related to remote medicine to African countries.

In remote medicine, the US is developing medical measuring devices for remote medicine, such as stethoscopes, electrocardiogram equipment, etc. However, because these devices use the land communications infrastructure, application of satellite communications is not necessarily progressing. Conversely, the value of utilizing satellite communications is high in India, which has a high need for remote medicine but inadequate land infrastructure.

In security-related uses, whether a country possesses dedicated defense communications satellites or not is important.

The start of HTS services will bring major reductions to the unit cost of communications services, and whether a country possesses technologies suitable for broadband communications or not is also a meaningful indicator when evaluating its technological capabilities.

Based on the above, Table 3-2b shows the evaluation of satellite communications / broadcasting missions by country. The indices considered here are the share of total communications, television broadcasting, remote learning, remote medicine, security, and mobile communications, etc.

Table 3-2b Evaluation of satellite broadcasting missions

Sector	Max.	US	Europe	Russia	Japan	China	India	Canada
Share of total Communications	2	1	1	1	1	1	2	2
Television broadcasting	2	2	2	1	1	1	1	2
Remote learning	2	1	1	1	2	1	2	1
Remote medicine	2	1	1	1	1	1	1	0
Security	2	2	1	2	1	2	0	0
Mobile communications, etc.	2	2	1	0	1	1	1	2
Total	12	9	7	6	7	7	7	7
Evaluation	5	4	3	2.5	3	3	3	3

(Maximum possible points: 12 ⇒ maximum possible score: 5, in increments of 0.5)

(c) Satellite communication/broadcasting companies

The number of satellite communication/broadcasting companies and their sales revenues are important indexes showing the degree of use of satellite communications in each country.

There was no major change in the order of companies providing fixed-satellite services (FSS). In Japan, SKY Perfect JSAT Corporation operates more than 10 geostationary communications satellites, and its actual sales rank 5th in the world. In terms of sales, the world's top-ranked satellite communication/broadcasting company is the US-affiliated organization Intelsat (International Telecommunications Satellite Organization), with main offices in Luxembourg and Washington; the second-ranked company is SES, also headquartered in Luxembourg; the third-ranked company is Eutelsat, headquartered in France; and the fourth-ranked is Canada's Telesat. Ranked 6th is Arabsat of Saudi Arabia, YahSat of the UAE in 7th, Thaicom of Thailand 8th, China Satcom of China 9th, and Hispasat of Spain in 10th position. Russia’s Russian Satellite Communications Company (RSCC) is ranked 11th, and India’s Antrix is ranked 15th. In addition to China Satcom, Hong Kong based Asiasat is ranked 16th, APT Satellite is 17th, and Asia Broadcast Satellite (ABS) in Bermuda is 19th. The combined revenues of these four companies exceed those of the Japanese company SKY Perfect-JSAT (as of 2014).

In Japan, BSat also ranked in the top 25 until 2009 because satellite broadcasting (BSS) companies were also included in the study. However, since 2010, that company has been excluded from the study, as the statistics in the source materials were limited to communications between fixed stations.

Suitable materials related to mobile satellite communication (MSS) was also not available, however the top ranking companies include Inmarsat headquartered in the United Kingdom, Iridium (US), Thuraya (UAE), Globalstar (US), and Orbcomm (US). Yet there are also many examples of launch/operation by several countries or by international organizations. In cases where the weight of a certain country is large, the company was counted as belonging to that country, but when the system is used relatively equally by several countries, for example, in the case of Inmarsat, the company is excluded from the evaluation. There has also been significant progress at O3b.

One of the more recent trends is satellite internet services based on mega-constellations made up of compact satellites, however these have not been included in the evaluation at this stage.

Specific data is shown in Table 3-2c.

Table 3-2c Number of satellite communication/broadcasting companies and sales revenues in 2014 (top 25)

Item	US	Europe	Russia	Japan	China	India	Canada
Number of companies	2	5	3	1	4	1	1
Sales (million USD)	2,547	4,428	448	446	727	185	794

Note 1: The No. 1 company, Intelsat (US$2,470 million) is headquartered in Luxembourg; however, because it has historically been considered a US company, it was listed as an American company in this calculation.

Note 2: The No. 19 company, ABS (US$130 million) is headquartered in Bermuda; however, because it has historically been considered a Chinese company, it was listed as Chinese company in this calculation.

Note 3; The 8 other companies in the top 25 include 2 in Asia, 3 in the Middle East, 1 in Australia, 1 in Central and South America, and 1 in Africa.

Source: Prepared by Secretariat based on various materials.

Table 3-2d shows the results of an evaluation of the satellite communication/broadcasting companies of each country based on the above data.

Table 3-2d Evaluation of satellite communication/broadcasting companies

Sector	US	Europe	Russia	Japan	China	India	Canada
Sales/Number of companies	2,547	4,428	448	446	727	185	794
Evaluation	4	5	2	2	3	1	3

(Maximum possible score: 5)

(d) Summary of satellite communications broadcasting

The total evaluation of the level of satellite communication/broadcasting, based on the data presented above, is shown in Table 3-2e.

Table 3-2e Total evaluation of satellite communications broadcasting

Sector	Max.	US	Europe	Russia	Japan	China	India	Canada
Technical development	10	10	9	1	5	1	0	0
Missions	5	4	3	2.5	3	3	3	3
Companies	5	4	5	2	2	3	1	3
Total	20	18	17	5.5	10	7	4	6
Overall Evaluation	10	9	8.5	3	5	3.5	2	3

(Maximum possible score: 20 ⇒ converted to maximum overall evaluation score: 10, in increments of 0.5)

(3) Earth observation

In earth observation, data on terrestrial environments, including images, is collected for diverse purposes, which include national security, national land conservation, environmental monitoring, international contribution, etc. The advanced countries are also utilizing the social implementation of space-based earth observation systems such as measures to combat global warming/environmental pollution, mitigation of disaster damage, use in primary industries, and the like. Earth observation was evaluated and summarized with each viewpoint, Mission, Sensor technology, Public use, Commercial use, and International Contribution.

The classification of viewpoints are the same as the previous study, however the evaluation method has been revised. The Mission viewpoint was simply reorganized into the observation domain. For the Sensor technology viewpoint, the compact constellation item that is being proposed more in recent years has been added, and observation from geostationary and other orbits have been redefined as real-time high-resolution observation. The Public use viewpoint follows the definition for the social contribution field revised in FY2015 by GEO (Group on Earth Observation), and includes new categories, with climate change in particular redefined as a basic field to revise the weighting of evaluation scores.

For reference, the following shows the earth observation satellites currently in operation by country.

a) Examples in the US

Earth observation

EOS-Terra/Aqua/Aura, GPM, QuikSCAT, SORCE, EO-1, Landsat, CloudSat, CALIPSO, OCO-2, Aquarius, CATS/ISS, RapidScat/ISS, GRACE, SMAP, KH, GeoEye, IKONOS, Worldview, Skybox, Flock

Meteorological observation　GOES, NOAA, DMSP, Suomi-NPP, OSTM/JASON-2

b) Examples in Europe

Earth observation

TerraSAR-X, TanDEM-X, RapidEye, SPOT, Sentinel, ERS, GOCE, SMOS, Cryosat, SWARM, SAR-Lupe, Helios, COSMO-SkyMed, Pleiades

Meteorological observation　MeteoSat/MSG, MetOp

c) Examples in Russia

Earth observation　Resurs, Kanopus, Kosmos

Meteorological observation　Elektro, Meteor

d) Examples in Japan

Earth observation　GOSAT, GCOM-W, GPM/DPR, ALOS-2, GPM, IGS, ASNARO

Meteorological observation　Himawari

e) Examples in China

Earth observation CBERS, Ziyuan, Huanjing, Tianhui, Gaofen, Haiyang, Yaogan, Jilin

Meteorological observation Feng Yun (geostationary and polar orbits)

f) Examples in India

Earth observation

SARAL, RISAT, Megha-Tropiques, RECOURCESAT, CARTOSAT, OCEANSAT,

Meteorological observation INSAT, KALPANA,

g) Examples in Canada

Earth observation RADARSAT, SCISAT, cooperative missions with EU and US

(a)Missions of earth observation

Types of missions will be examined as one indicator of the technical capabilities of the respective countries in the field of the earth observation satellites. In other words, the diversity of missions is indicative of the range of earth observation capabilities (technical capabilities).

Evaluation standards for meteorological observation are scored by whether a country currently operates geostationary satellites that are part of a meteorological observation satellite network, and whether a country currently operates geostationary satellites, with 2/1 points given to each. Other applicable fields were given 1 point if a country operates a satellite with the purpose of observations in that field or includes core observation parameters, with an added point if multiple satellites are in operation.

The evaluation results are shown in Table 3-3a.

Table 3-3a Evaluation of earth observation mission diversity by country

Missions	Max.	US	Europe	Russia	Japan	China	India	Canada
Meteorological observation	3	3	3	3	2	3	2	0
Atmospheric observation	2	2	2	1	2	2	2	1
Marine observation	2	2	2	1	2	2	2	1
Land observation	2	2	2	1	2	2	2	2
Total	9	9	9	6	8	9	8	4
Evaluation	10	10	10	6.5	9	10	9	4.5

(Maximum possible score: 9 ⇒ converted to maximum overall evaluation score: 10, in increments of 0.5)

(b) Earth observation sensor technology

In evaluating the types and performance of earth observation sensor systems, the evaluation indexes are not limited to sensor design capacity, but also include technical capabilities related to parts, which are key to this area of technology. Moreover, because interpretation of the obtained data (analytical capabilities) has a strong correlation with the levels of the related sciences in each country, this was a consideration during the evaluation.

Earth observation sensors can be broadly divided into optical sensors and radio sensors, and can be further classified into four categories depending on whether they are active or passive (one exception being gravitational field sensors using accelerometers). Depending on the object of observation, earth observation is evaluated in the three dimensions of horizontal/vertical resolution, wavelength resolution, and temporal resolution (observation frequency). For example, temporal resolution is a priority in the mission of weather satellites, horizontal resolution is a priority in the mission of land observation satellites, and wavelength resolution is generally a priority in the mission of environmental observation satellites. Since there is a tradeoff among these various capacities when examining missions, it is not possible to satisfy all of these performance requirements with a single satellite. More recently, satellite users have adopted an approach of compensating for deficiencies in one area, for example, by using multiple satellites to increase observation frequency. In the previous generation, missions were carried out by using large-scale platforms such as the US EOS series, Europe's Envisat, the Japanese ADEOS series, and others. In recent years, however, small-to medium-scale single missions with satellites carrying approximately 1 or 2 sensors have continued to become the norm from the viewpoints of robustness as a system and flexibility in development planning. Although orbiting weather satellites (e.g., JPSS (US), MetOP (Europe)) have been somewhat downsized, use of the platform system is continuing in this area from the viewpoint of securing a simultaneous observation capability with multiple onboard sensors. On the other hand, formation flight has been highly evaluated in the field of single mission satellites. The US A-TRAIN is a representative example, and Europe has also begun study of this approach. In light of this development, it is possible that missions using large-scale platforms may be replaced by this mode.

For this study, an item was added to the evaluation for observation systems that use the small-scale satellites that are continually being announced during system construction in recent years. Systems such as Skybox have become the norm for observation for their more compact and diverse approach to achieving both temporal and spatial resolution. In the past, there were restrictions with the payload observation equipment due to increasingly compact size, as well as issues related to rising costs due to having to source multiple satellites. Yet with the Skybox example, these issues can be avoided by simplifying the attitude control system required for ordinary observation satellites as far as possible, ensuring the same level of observation equipment as larger systems by instead sacrificing observation direction control. Despite the lack of observation direction control, carrying out multiple observations increases the possibility of covering a larger observation area, which makes systems such as Google Maps effective for the observation of earth surface conditions where there are likely to be minimal changes over time.

The satellite with the world's highest spatial resolution is the US reconnaissance satellite Keyhole (KH), which is thought to have resolution of around 15cm (although the actual capability is unknown). Among satellites whose capabilities have been disclosed, the US commercial imaging satellite WorldView-3 has resolution of 31cm. The limit of commercial surface resolution was relaxed to 25cm in 2014, and systems capable of resolutions close to that limit are expected to be released soon. Meanwhile, there is a tradeoff between whether to prioritize the earth surface resolution or wide-area photography, and the range that can be photographed at one time is generally small when surface resolution is high. This also means that the frequency of photography is low, and thus the balance between resolution and wide-area characteristics needs to be optimized depending on the purpose of photography (buildings on land/roads/rivers/vehicles/human beings, etc.) In principle, optical and synthetic aperture radar (SAR) complements the observational features of optical sensors. This means visible light observation is not possible at night and during cloudy weather, but when photography is possible, detailed information can be collected. In contrast, although the resolution of radar is inferior to that of visible light, radar enables observation under all weather conditions, including at night. The main cause of the poor radar resolution used to be bandwidth restrictions due to frequency usage policies, however with X-band radar being internationally revised as an available bandwidth in recent years, a surface resolution rivaling that of optical resolution is expected to become available.

The C-band, X-band and L-band has been set aside for SAR for use with satellites. Plans have also been announced for the Ku-band, P-band and S-band, with greater diversity with frequencies being forecast, as well as systems capable of features such as simultaneous observation using multiple frequencies. Technical development is also anticipated for systems such as those capable of real-time interferometric observations using tandem flight as demonstrated with TanDEM-X. In Japan, the L-band SAR on board JERS-1 through to ALOS-2 is highly competitive from its track record with long-term observations. Multiband imagers are imagers which have a narrowband of approximately 30 across a wide spectral band from the near ultraviolet to the infrared regions. Although it is difficult to improve surface resolution, qualitative observation such as observation of objects over a wide region can be performed by reducing the amount of light by adopting a narrowband. The most widely-used imager of this type is MODIS (Moderate Resolution Imaging Spectroradiometer) on the US EOS, which has been superseded by VIIRS (Visible Infrared Image Radiometer Suite) of Suomi-NPP as a successor sensor in recent years. The imager used in Japan is SLGI on GCOM-C. The surface resolution of VIIRS is 375m, in contrast to which SGLI (Second-Generation Global Imager) will realize resolution of 250m, showing the superiority of the Japanese specification. While the launch of the Japanese GCOM-C was delayed, development of Sentinel in Europe has progressed as per plans, bringing about a change in the competitiveness between Japan and Europe. China launched the FY-3 and has started announcing the results of qualitative observations using multi-wavelength observation, however this technology is still lagging behind examples in more advanced countries, and with novelty and assurances of precision yet to be achieved.

Spectrometers include devices which detect gases (e.g., ozone, CO_2, etc.) in the atmosphere in the infrared region and devices which qualitatively evaluate objects in the visible light region. The key point of both types is that the properties of substances are evaluated by measuring their spectral characteristics in an extremely narrow band. Examples in the west include Sciamachy or IASI of Europe, and AIRS, OCO and CrIS in the US. In addition to GOSAT-FTS for observation carbon dioxide, and HISUI designed for the ISS, Japan is planning experiments demonstrating the use of small-scale satellites.

The United States is the leader in laser radar (LADAR), followed by Europe. The fact that the life of the high output laser transmitters used in earth observation did not perform as designed was a common technical problem worldwide. However with CALIPSO, the US established long-life laser transmitter technology for earth observation. Europe is currently developing an ultraviolet laser transmitter for installation in the Aelous and EarthCARE, and with the addition of a Doppler measurement function is seeking to overtake the US. Japan has developed a compact laser altimeter for use in lunar exploration, however it is currently limited to the level of research into demonstrations of Lidar observation of vegetation environments on the ISS for use with earth observation purposes.

While the geostationary orbit meteorological satellites of each country use meteorological sensors developed by that particular country, Japanese meteorological satellites actually use sensors imported from the US. This essentially means that Japanese development capabilities for earth observation sensors from geostationary satellite orbits is starting to become lacking. Advanced countries are discontinuing development in which multispectral imagers and sounders developed for use in circular orbit is transplanted to geostationary satellite, as those devices are comparatively simple multichannel sensors and thus have outmoded specifications.

Only the US (DSP) and Russia have already developed practical applications for sensors for early warning satellites used for real-time high-resolution observations, but the technical details of those devices are not known. Europe completed the launch of its engineering test satellite Spirale, with Airbus announcing a civilian high-resolution real-time observation satellite system called GO-3S. China reported that the Gaofen 4 launched in 2015 is capable of real-time observation with a 50m surface resolution. India is also developing a real-time observation satellite called GISAT with a 60m resolution. Japan as the potential technical capability for such systems, however is only at the research stage.

A closer look at observation sensors by country reveals that the US and Europe are developing almost all types of sensors available.

Russia has made partial advances in early warning satellites and electromagnetic wave satellites for earthquake prediction, but nevertheless has stagnated in the sense of variation and modernization of observation sensors. China is reaping the benefits of cooperation with Europe as well as development of an extremely large number of sensors. The country has the capability to develop the minimum hardware required, however is still developing the methods and techniques for calibrating, validating and applying observation data. India is slightly behind China with regards to research and development of observation system hardware, however is thought to be close to matching those levels. As a national policy, Canada has adopted a strategy of narrowing the range of development to certain technologies and aiming to be the world's leader in those fields; it now effectively controls several key technologies, including C-band SAR satellites, Fourier spectrometers, and W-band high output transmitters, among others.

Due to the scale of Japan's space development budget, this country cannot undertake all the missions in the same range as the United States and Europe, but covers the majority of technologies on a research level. In areas where it has begun satellite development as a mission, Japan has secured its international status by demonstrating either the world's only technology or the world's high performance. Examples of "world's only" technologies include the L-band SAR system of ALOS, Ku/Ka band precipitation radar of GPM, W-band Doppler radar of EarthCARE, and Fourier spectrometer for CO2 measurement of GOSAT. Moreover, AMSR of GCOM has practically become the global standard for microwave scanner sensors. As a high performance multi-wavelength radiometer equivalent to VIIRS in morning orbit, SGLI is expected to become an irreplaceable sensor. With the exception of laser radar, Japan is continuing to surpass the US and Europer in the R&D stage of basic technologies in the same fields, and in the future, the country will advance to the stage envisioning social implementation by combination use of satellites. As the continuity of the earth observation satellite series will be the core of that effort, assurance of continuity as industrial/public use infrastructure will be necessary.

For the evaluation, 1 point was given if sensors for various fields were developed and used in that country, and a further 1 point added if the results of observations from those sensors were sufficiently recognized throughout international institutions and capable of providing reliable data.

The results of an evaluation of earth observation sensor technologies is shown in Table 3-3b.

Table 3-3b Evaluation of earth observation sensor technologies

Sensor technology	Max.	US	Europe	Russia	Japan	China	India	Canada
Visible high-resolution	2	2	2	1	2	1	1	0
Synthetic aperture	2	2	2	0	2	1	0	2

radar								
Multiband sensor	2	2	2	1	2	1	0	0
Spectrometer	2	2	2	0	2	0	0	1
Laser radar	2	2	1	0	0	0	0	0
Meteorological sensors	2	2	2	2	0	2	2	0
Real-time high-resolution observation	2	2	1	2	0	1	1	0
Small-scale formation	2	2	0	0	0	0	0	0
Total	16	16	12	6	8	6	4	3
Evaluation	10	10	7.5	4	5	4	2.5	2

(Maximum possible score: 16 ⇒ converted to maximum overall evaluation score: 10, in increments of 0.5)

(c)Public use (weather, disaster-prevention, environment)

How the results of such a large number of satellite missions is collected for contribution to public use is a subject of much discussion, particularly in the US and Europe where general technical development is nearing completion. The "Global Earth Observation System of Systems (GEOSS)" is a global initiative run by the Group on Earth Observations (GEO). The features of GEOSS are social applications of monitoring and observation data in 9 fields that can bring benefits to society, such as disasters, health, weather, and agriculture, by integrating observation with in-situ monitoring systems, including land, marine, and atmospheric observation and others, in addition to observations from space. In terms of satellites as such, the United States has already established the indispensable social infrastructure, centering on defense, and has partially completed social implementation.

In Europe, countries within the EU are cooperating with the development of a system for environmental monitoring and security covering the EU and Africa under the name Copernicus: The European Earth Observation Programme (formerly known as GMES: Global Monitoring for Environment and Security). In addition to the implementation and operation of satellites, various points have been finalized for the actual use of satellite data for public purposes. Copernicus is also Europe's contribution to GEOSS.

In addition to the cooperation with meteorological satellite observations outlined later, Japan's contribution to GEOSS will focus on 3 of the 9 fields of social use, "Global warming/changes in global carbon cycle," "Climate change/changes in water cycle," and "Disasters". Development of satellite systems applicable to other fields have been outlined and organized in a 2005 report by the Space Activities Commission Special Committee for Earth Observation. In parallel with this, Japan has researched a data integration and analysis system (DIAS) for integration and use of the obtained satellite observation data and ground observation data. Yet there are currently no systems in place for social infrastructure or implementation throughout society, and the use of satellite systems as infrastructure or social implementation will need to be reviewed over the long term in line with Europe and the US.

Russia's meteorological agency is participating in cooperation in meteorological satellite observation, as described in the following, but has virtually no actual record of participation in GEOSS. However, in recent years, the Russian company ScanEx and others have been involved in high order use of data, also including foreign satellites, for example, in forest and river management and the like.

China and India have made the main purpose of their own earth observation satellites to address current issues such as land use in their own country or surrounding regions, or meteorological observations. Canada is devoting considerable effort to the observation of domestic water resources by utilizing the performance of its radar satellites.

The 10-year plan for GEOSS has also been updated, with initiatives such as Future Earth, aimed at bringing together and enhancing sciences and humanities, being held based on the premise of social implementation.

Regarding meteorological observation, the World Meteorological Organization (WMO) has constructed World Weather Watch (WWW), made up of groups of geostationary satellites, comprising Himawari (Japan), GOES (US), Meteosat (Europe), Electro (Russia), INSAT (India), FY-2 (China), COMS-1 (Korea), and groups of circular orbit satellites, comprising DMSP, NOAA, and JASON (US), MetOp (Europe), Meteor (Russia), and FY-3 (China). This global observation system uses the geostationary satellites of each country to cover the entire planet, allowing the mutual exchange of data. While Japan is making an international contribution with its geostationary satellites, it still depends on foreign parts for its mounted meteorological sensors, and also currently has no circular orbit satellites for weather observations. Observation data from circular orbit satellites is dependent on the current circular orbit satellites of each country, as well as JAXA’s R&D circular orbit satellites.

For the evaluation, 2 points were given for integrated systems if they are designed for integrated operation of observation data from various satellites. The maximum score was given for weather if almost all items were covered, depending on how well observation of essential climate variables (ECVs) were covered and if they are used for climate assessments. Instead of simply the presence of observation data, evaluations focused on whether or not that observation data was being interpreted and used. For other items, 1 point was given if there were efforts being made to consider the use of observation data, another 1 point was added if the data had already started to be used, and further points added if there was clear evidence of data being regularly used for that item.

Table 3-3c shows the results of an evaluation of public use of earth observation satellites based on the conditions outlined above.

Table 3-3c Evaluation of public use of earth observation satellites

Sector	Max.	US	Europe	Russia	Japan	China	India	Canada
Integrated systems	2	1	2	0	1	0	0	0

Weather	4	4	4	3	3	2	2	1
Biodiversity	3	1	1	0	1	0	0	0
Disaster	3	3	3	3	3	3	3	3
Energy/resources	3	2	2	2	1	1	0	0
Food/agriculture	3	2	2	1	1	1	0	1
Infrastructure/transportation	3	1	1	1	1	1	0	0
Public sanitation	3	1	1	0	1	1	0	0
Urban development	3	1	1	0	0	0	0	0
Water resources	3	3	2	1	3	1	2	0
Total	30	19	19	11	15	10	7	5
Evaluation	10	6.5	6.5	3.5	5	3.5	2.5	1.5

(Maximum possible score: 30 ⇒ converted to maximum overall evaluation score: 10, in increments of 0.5)

(d)Commercial use (satellite manufacture/sale, satellite imaging sale)

Europe is the leader in the manufacture and sale of earth observation satellites, and companies including Surrey Satellite Technology Ltd. (SSTL; maker of small-scale satellites), Airbus, TAS, and others have multiple results of satellite sales to emerging countries in Africa, Korea and Asian countries. Canada is also developing the German RapidEye by using RADARSAT satellite technology. In Korea, Satrec Initiative is manufacturing small-scale earth observation satellites for Malaysia, the United Arab Emirates, and Spain.

China is in joint development of satellites with Brazil, and has launched 4 satellites up to 2014. It has also received orders for small-scale earth observation satellites from Venezuela, and has already launched them. Russia and India have no records of manufacturing earth observation satellites for other countries. The United States substantially manufactured Korea's KOMPSAT-1, and exports weather satellite sensors to Japan.

Japan is developing low-cost satellites such as ASNARO, envisioning sales to other countries. Although the mid-sized countries of Asia also have needs for ALOS level satellites, Japan still has no record of exports of earth observation satellites, with the exception of the ocean color imager OCI for Formosat-1 (Taiwan) in 1999.

From the viewpoint of using satellite imaging for business, companies in the US and Europe have recorded sales in the form of sale of reception rights to users who can operate receiving stations. Users without receiving stations need to purchase the images. The US, Europe (France, Germany), India, Canada, and other countries sell images acquired by their own satellites. In the US, intelligence agencies have become "anchor tenants," establishing the base for long-term sales of high-resolution images by the company Digital Globe (which merged with GeoEye). In Europe, Astrium GEO information services sells commercial images acquired by SPOT, Pleiades, TerraSAR, and other satellites. In India, Antrix sells images from ISRO's earth observation satellites to customers around the world. Even in Canada, RADARSAT images are sold by MDA.

In Japan, the private company PASCO, the RESTEC foundation and others have sold commercial satellite images from ALOS, as well as from the satellites of other countries.

In Russia, IKI Data Distribution Service sells images from NOAA and Russian satellites. There are also numerous other companies such as ScanEx and SOVZOND. In China there are companies that sell images, including Twenty First Century Aerospace Technology Co., Ltd. (21AT) and Chang Guang Satellite Technology Co., Ltd. 21AT acquires images through exclusive operation of the 3 DMC3 satellites launched by England's SSTL in July 2015. Chang Guang is aiming to sell commercial images by operating Jilin, an earth observation satellite launched in October 2015 exclusively by Jilin Province.

In this evaluation, 1 point was given for countries exporting sensor units, sub-system level or small-scale satellite level commercial use, with 1 point added for countries with commercial use of medium-scale or larger satellites. Another 1 point was added if the country provides reception rights, while sales of images were also evaluated based on whether images were actually for sale, and their availability.

Table 3-3d shows the results of an evaluation of commercial use of earth observation satellites based on the conditions outlined above.

Table 3-3d Evaluation of commercial use (satellite manufacture/sale, satellite imaging sale)

	Max.	US	Europe	Russia	Japan	China	India	Canada
Satellite manufacture and sale	2	1	2	0	0	1	0	1
Sale of reception rights	1	1	1	0	0	0	0	0
Sale of images	2	2	2	2	1	1	1	1
Total	5	4	5	2	1	2	1	2
Evaluation	5	4	5	2	1	2	1	2

(Maximum possible score: 5)

(e) International cooperation

Earth observation systems using satellites cannot be covered solely by larger countries such as the United States or Europe, for example. Even regions cannot be covered independently, and the acquired observation results cannot be used in their entirety. Based on these facts, closer international cooperation is essential to ensure the commercial viability of earth observation systems, to develop a framework for covering the observation needs that might be lacking in a particular country, and supplying any access observation results to other countries. Growth of such systems needs to go through various processes, the first being enhancing observation capabilities in a particular country, then developing an observation network with regions neighboring the country's economic area, and finally linking with other regions to form a global observation system. GEOSS is an initiative by the major space agencies aimed at developing a global observation system, however the time has come to develop a framework for international cooperation covering each region. With this in mind, the level of international cooperation was the focus of this evaluation. Evaluations of meteorological observation are not covered here as that field has already by covered in the preceding evaluation, so the International Disaster Charter has been used for the evaluation as another example of commercial application of the satellite observation framework. Another viewpoint used for the evaluation was whether a regional cooperation framework has been established in each region. In the evaluation, each of these have been given 4 points, with 1 point for participation in the Disaster Charter, 1 to 2 points depending on the frequency that satellites were actually used, and 1 point given to Europe for operating and managing the charter. Regional cooperation was evaluated with 2 points given if a regional cooperation system is in place with that country as the leader, with 1 to 2 points given according to the results of the system (including the number of continual years of operation, number of participating countries, capacity building, and level of public use technology).

a) Participation in the International Disaster Charter

The International Disaster Charter is a system by which countries which possess earth observation satellites provide useful image data for disaster countermeasures to countries affected by large-scale, wide area disasters such as earthquakes, tsunamis, floods, etc. In addition to the US, Europe, Russia, Japan, China, India, and Canada, Argentina and Korea also participate in this system. Japan had temporarily ceased contributing to the system following the shutdown of ALOS, however ALOS-2 was launched as its successor, resuming contributions with its synthetic aperture radar.

The participating organizations of each country are as follows.

US, 2 organizations: NOAA, USGS (Digital Globe, GeoEye)

Europe, 5 organizations: ESA, CNES (France, Airbus, NSPO (Taiwan), DLR (Germany), DMCii (UK, Algeria, Nigeria, Turkey, EUMETSAT)

One organization each for the following. Russia Roscosmos, Japan JAXA, China CNSA, India ISRO, Canada CSA, Argentina CONAE, Korea KARI, and Brazil INPE

b) Regional cooperation

1) Asia/Pacific region

In the Asia/Pacific region, Japan is the leader of the Asia Pacific Regional Space Agency Forum (APRSAF, an organization with 40 participating countries, including European countries, the United States, China, and Russia, and 26 international organizations, including ESA). The activities being carried out under the framework of the APRSAF are the regional disaster-prevention framework Sentinel Asia, the environmental observation framework SAFE, and the climate change framework Climate R3, thus creating regional frameworks in these respective areas. China leads the separate Asia Pacific Space Cooperation Organization (APSCO, 8 participating countries). APSCO itself also participates in APRSAF.

2) Europe

In Europe, the ESA is the core of international cooperation organizations in the European region and is also continuing to encourage use in the African region by activities of the TIGER Initiative. Activities of the DRAGON Program over the Chinese mainland are also continuing to encourage use in China.

Table 3-3e shows the results of an evaluation of international contribution based on the above.

Table 3-3e Evaluation of international contribution

	Max.	US	Europe	Russia	Japan	China	India	Canada
International Disaster Charter	4	3	4	1	2	1	1	2
Regional cooperation	4	0	4	0	4	3	0	0
Total	8	3	8	1	6	4	1	2
Evaluation	5	2	5	0.5	4	2.5	0.5	1.5

(Maximum possible score: 8 ⇒ converted to maximum overall evaluation score: 5, in increments of 0.5)

(6) Overview of emerging countries

Satellite development in Korea began from KITSAT, which was based on SSTL's bus. More recently, Korea developed the Arirang (KOMPSAT) series of circular orbit satellites based on overseas technologies introduced from the United States and Europe. The sensors in use are satellites ordered from AirBus and Thales in Europe. Where geostationary satellites are concerned, Korea acquired COMS, which also uses a European satellite bus. The Satrec Initiative is the main form of small-scale satellite, and exports to other countries have been seen recently. Although Korea has a small-scale satellite development capability, it must unavoidably depend on purchases from other countries for medium- to large-scale practical satellites. It also seems that domestic production capacity in Korea is insufficient for core parts (optical systems, sensors, etc.) required for the development of sensor equipment. Korea is expected to promote independent technology acquisition with small-scale satellites in parallel with acquisition of practical satellites by introducing foreign technologies.

Brazil, Argentina, and certain other countries have carried out joint development of observation sensors, mainly with NASA. As these observation sensors include advanced instruments in certain niches, it is judged that those countries have partially acquired technologies in this field. In recent years, both Brazil and Argentina acquired their own small-scale earth observation satellites with international cooperation from the US, China, etc.

In the past, Vietnam, Thailand, and others have conducted earth observation activities utilizing satellite observation data of other countries, but now operate their own satellites like VNREDSAT (Vietnam) and THEOS-1 Thailand), and appear to continue such trends. Other countries like the Philippines have also expressed new interest in acquiring their own small-scale satellites, in a sign of a budding space industry in emerging countries.

(g) Summary of earth observation

Table 3-3f shows the results of a comprehensive evaluation of the levels of earth observation fields in the 7 main countries based on the above study results. Tremendous technological growth is evident in China and India compared to the previous study. While Europe is lagging behind the United States slightly with technology, it has moved ahead with systems using earth observation for public purposes, with the results demonstrating the best balance for earth observation programs that also cover utilization and international cooperation systems.

Table 3-3f Total evaluation of earth observation

Sector	Max.	US	Europe	Russia	Japan	China	India	Canada
Mission diversity	10	10	10	6.5	9	10	9	4.5
Sensor types/performance	10	10	7.5	4	5	4	2.5	2
Public use	10	6.5	6.5	3.5	5	3.5	2.5	1.5
Satellite sales/image sales	5	4	5	2	1	2	1	2
International contribution	5	2	5	0.5	4	2.5	0.5	1.5
Total	40	32.5	34	16.5	24	22	15.5	11.5
Overall evaluation	10	8	8.5	4	6	5.5	4	3

(Maximum possible score: 40 ⇒ converted to maximum overall evaluation score: 10, in increments of 0.5)

(4) Navigation and Positioning

Positioning satellites are satellites which transmit precise time data and data on the position of the satellite itself in order to determine the position and time of a user's receiving terminal. This process is called "positioning". To determine the time and position of the user’s receiving terminal precisely, it is necessary to receive signals from at least four satellites and calculate the distance between the terminal and each of the positioning satellites. Therefore, it is necessary to implement and operate a satellite positioning system consisting of multiple positioning satellites in order to make it possible to determine a user's position/time in the service area at all times.

A satellite positioning system which covers the entire globe is called GNSS (Global Navigation Satellite System); this type of system requires from 24 to 30 medium earth orbit (MEO) satellites. At present, two such systems are in operation, the American GPS and the Russian GLOSNASS. China’s Beidou and Europe’s Galileo systems are currently in the implementation stage.

In contrast to the above-mentioned GNSS, systems which provide regionally-limited service are called RNSS (Regional Navigation Satellite Systems). Japan’s Quasi-Zenith Satellite System (QZSS) and India’s IRNSS are currently in the implementation stage as RNSS. Systems which augment GNSS are called SBAS (Satellite Based Augmentation System). Civil navigation services have already been started by the United States, Europe, and Japan, and India and Russia are developing SBAS systems.

The evaluation in this study focused on three points, namely, system construction technology, satellite constellation performance, and GNSS augmentation technology.

(a)System construction technology

Among the technologies necessary in construction of a satellite positioning system, the most important index is considered to be SIS-URE (Signal-In-Space User Range Error). Therefore, the present evaluation was performed based on SIS-URE, and the results were adjusted by factors which also consider onboard atomic clock and precision orbit/clock offset estimation technology.

○ SIS-URE

The most important index when comparing the performance of satellite positioning systems is the capability to estimate precisely the positioning satellite orbit and system time-system deviation, perform propagation forecasting of this over a specified time period, and supply this as a navigational message in a form that can be used in positional calculations by the user.

Table 3-4a shows the latest SIS-URE outlined in the published documentation for each system at the United Nations’ 10th International Committee on GNSS (IGC) held in November 2015, and previous sessions.

In the case of GPS and GLONASS, these are Root Mean Square (RMS) values for all satellites including older generations, while figures for other systems are for individual satellites and the evaluation only includes new satellites. This must be noted when making comparisons, however GPS that has continued to perform reliable over the long term, with updated satellites and ground systems exhibit the highest level of performance. While the evaluation of Japan's QZSS (Quasi-Zenith Satellite System) is limited to one satellite, this satellite has achieved SIS-URE performance equal to that of the most recent satellites in the GPS.

Table 3-4a SIS-URE of satellite positioning systems

Country	Satellite positioning system	SIS-URE
US	GPS	0.7m (RMS of all operational satellites)*1
Russia	GLONASS	1.8m (RMS of all operational satellites)*2
China	Beidou	0.6-1.3m (RMS)*3
Europe	Galileo	1.26m (first IOV (RMS))
Japan	QZSS	0.4m (Michibiki (RMS))
India	IRNSS	Around 4-5m*4

*1: SIS-URE of the most recent satellites in GPS (IIRM and IIF) is 0.4m (RMS).

*2: According to Russian published documentation at the 4th ICG. In later ICG materials, Russia published results for SIS-User Positioning Error.

*3: RMS conversion of the 1.25 to 2.6m listed in published documentation at ICG (14 satellites, 95% error for each satellite)

*4: From conversion listed in July and August, 2015 editions of Inside GNSS

○ Onboard atomic clocks

Whether a country has the domestic capability to manufacture atomic clocks for installation in positioning satellites, and whether the clocks manufactured by a country are stable or not, are important considerations in system construction.

Based on the specifications published by the ICG and papers published by related scientific societies, Table 3-4b shows whether the countries in this study manufacture atomic clocks which are incorporated in positioning systems or not, and if so, the stability of the clocks (Allan deviation/day). The rubidium (Rb) atomic clock for the US GPS Block-IIR satellite has stability of 1-8 x 10^{-14}, and also has the largest numbers of record of orbital operation. With the exception of several units, its stability is 2 x10^{-14} or better. Europe's Galileo is equipped with a passive hydrogen maser atomic clock in addition to a Rb atomic clock. The evaluation shows the performance evaluation results for clocks installed in the experimental satellites GIOVE-A and -B, which have been published at present. The US has the highest level of performance in Rb clocks, while the performance of Europe's passive hydrogen maser atomic clock is equal or superior to that of the US.

Table 3-4b Atomic clock manufacturing capability and clock stability

Country	Satellite positioning system	Onboard atomic clock manufacturing capability	Atomic clock performance (stability)
US	GPS	○ (Cs, Rb)	1-8 $\times 10^{-14}$@1day (Block-IIR, Rb on IIR)
Russia	GLONASS	○ (Cs)	2-8 $\times 10^{-14}$@100000s*1
China	Beidou	○ (Rb)	2.5-9.4 x10-14@1day
Europe	Galileo	○ (passive hydrogen maser, Rb)	8 $\times 10^{-15}$@1day (passive hydrogen maser on GIOVE-B) 5 $\times 10^{-14}$@1day (Rb on GIOVE)
Japan	QZSS	x*2 (Rb)	―
India	IRNSS	X*3 (Rb)	―

*1: According to specifications published at 4th ICG (2008).

*2: The Rb atomic clock on Japan's Michibiki was imported from the US. As a domestically-manufactured onboard atomic clock, Japan's NICT (National Institute of Information and Communications Technology) carried out development of a passive hydrogen maser type to the engineering model development test stage, but due to issues with the mass and life of the clock, installation on the Michibiki was canceled.

*3: The atomic clock on the IRNSS currently being developed appears to be an imported component.[1]

○ Precise orbit estimation

The results of various organizations are applied to the satellite positioning systems of their respective countries. For example, the orbit/clock estimation software of NASA/JPL, which is the analysis center of the International GNSS Service (IGS) will be adopted in the ground control stations of America's next-generation GPS. Therefore, whether countries have their own IGS analysis centers or not was investigated by comparing the orbit/clock estimation technologies at the present time. A list of IGS analysis centers is shown in Table 3-4c. Note that although no Japanese organization was selected as an IGS analysis center, JAXA is currently developing MADOCA (MultiGNSS Advanced Demonstration tool for Orbit and Clock Analysis); based on this, Japan was evaluated as having technical capabilities equivalent to those of countries that possess IGS analysis centers.

Accordingly, since Japan is developing MADOCA, it is considered to have precise orbit/clock estimation technology on the same level as the US, Europe, China, and Canada, which have IGS analysis centers. While Russia does not have any agencies operating as an IGS analysis center level, the results of the GLONASS precise orbit/clock estimations released by the Information Analysis Center have the same level of

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1 June 27, 2013 article in Hindou
http://www.thehindu.com/sci-tech/technology/india-prepares-to-establish-navigation-satellite-system/article4853847.ece

precision as the estimation results of the IGS analysis center. India does not yet participate with IGS or release the results of precise orbit/clock estimations, so its current technical level for precise orbit/clock estimations is thought to be low in comparison to other countries.

Table 3-4c Organizations hosting IGS analysis centers and their countries

Organization		Country
Center for Orbit Determination in Europe, AIUB	CODE	Switzerland
European Space Operations Center（ESA）	ESA	Germany
Geodetic Observatory Pecny,	GOPE	Czech
GeoForschungsZentrum	GFZ	Germany
GRGS-CNES/CLS, Toulouse	GRG	France
Jet Propulsion Laboratory,(JPL/NASA)	JPL	US
Massachusetts Institute of Technology(MIT)	MIT	US
National Oceanic and Atmospheric Administration (NOAA)/ NGS	NGS	US
Scripps Institution of Oceanography	SIO	US
U.S. Naval Observatory(USNO)	USNO	US
Natural Resources Canada(NRCan)	NRCan	Canada
Wuhan University	WU	China

From the above, assuming a maximum raw score of 6 for SIS-URE, scores were assigned as follows: 1m: 6, 1-1.5m: 4, 1.5m: 2, with 2/0 assigned depending on whether or not a country has atomic clock manufacturing technology. Additionally from the viewpoint of whether or not countries have a high level of precise orbit/clock estimation technology, which is the benchmark for whether or not the basic technology is available for improving SIS-URE in the future, countries with an organization that operates as an IGS analysis center (or countries with an organization that has released a similar level of orbit/clock estimation results) were given 2 points, and countries without an organization that currently regularly releases precise orbit/clock estimation results were given 0 points. Thus a comparative evaluation was conducted with a maximum score of 10 points. The evaluation results are shown in Table 3-4d.

Table 3-4d Comparison of system construction technologies

Sector	Max.	US	Europe	Russia	Japan	China	India	Canada
SIS-URE	6	6	4	2	6	4	2	—

Atomic clock	2	2	2	2	0	2	0	—
Precise orbit estimation	2	2	2	2	2	2	0	2
Evaluation	10	10	8	6	8	8	2	2

(Maximum possible score: 10)

(b)Constellation

Constellation means a technology for coordinated operation of multiple satellites. Constellation is a critical technology, because, unlike satellites for other applications, positioning is a service which is achieved based on information from 24 to 30 satellites. In the present study, an evaluation was made considering the current condition of system implementation and operation, operational results (record of supplying stable service), and the DOP (Dilution of Precision) which can be provided.

○ Condition of system implementation of respective countries

The United States inaugurated GSP in the 1950s as a military system and carried out development and implementation thereafter on an ongoing basis. As of the end of 2015, the US had 31 operational satellites. Civil signals are transmitted on frequency L1C/A (1575.42MHz), and military signals are transmitted on two frequencies, L1 (1575.42MHz) and L2 (1227.60MHz).

As new civil signals, the US has begun transmission on frequency L2C (1227.60MHz) from the Block-IIR satellites and on L5 (1176.45MHz) from the Block-IIF satellites. As of the end of 2015, 7 IIRm satellites and 11 IIF satellites had been launched and were in operation. The addition of a L1C signal to the L1 band is planned beginning from the Block-III satellites, which are scheduled for launch starting in 2016. The start of service using modernized GPS signals is expected around 2018 for L2C, around 2021 for L5, and around 2026 for L1C.

These modernized signals will have dedicated ranging (distance measurement) channels to enable positioning under more adverse receiving environments. Among various other improvements, the code length of ranging codes will be improved, the chip rate will be increased, etc.

Russia launched its first GLONASS positioning satellite in 1982 and completed a system of 24 satellites in December 1995. However, due to the economic confusion following the collapse of the former Soviet Union, the number of operable satellites declined to six in 2001. The 24 satellite system was restored in November 2011. As of the end of 2015, Russia had 27 satellites in orbit and operating, including 2 test satellite and 2 satellites being checked. The M series of satellites is currently in operation. However, addition of CDMA signals is scheduled from the next-generation K series, considering interoperability with other GNSS.

China is planning to construct a satellite positioning system called the Beidou Navigation Satellite System in steps, and plans to construction a global positioning system in the 3rd step.

In the first step, 2-way distance measurement between an S-band ground station and user terminal was performed via satellites using two geostationary satellites. In this system, the user’s position was calculated by the ground station and the user was notified via the satellite.

The second step is a 1-way distance measurement system like that in other GNSS. It provides a regional system with a service area covering China and the neighboring region of Asia and Oceania (latitude 55°N to latitude 55°S, longitude 55°E to 180°E). Launches began in 2007. System construction was completed in December 2012, and the transition to regular service was announced. As of the end of 2015, service is provided by a total of 13 satellites, comprising 5 geostationary earth orbit(GEO) satellites, 5 inclined geosynchronous satellite orbit (IGSO) satellites with 8-shaped ground tracks like those of quasi-zenith satellites, and 3 medium earth orbit (MEO) satellites. The services provided are public signals for civil use, security signals, which are assumed to be for military use, wide-area augmentation, and short messages.

In Step 3, the regional system will be extended to a global system, targeting completion around the year 2020. This system will comprise a total of 35 satellites, consisting of 5 GEO satellites, 3 IGSO satellites, and 27 MEO satellites. While the positioning method will be the same as in step 2, the frequencies used will be changed in the 3rd step in order to secure interoperability with other GNSS. Launches began in 2015, with testing in progress as of the end of 2015. The total of 4 satellites that make up step 3 of the global are 2 IGSO satellites and 2 MEO satellites.

In the Galileo system being constructed by Europe, a total of 30 satellites will be placed in 3 orbits, comprising 9 satellites and 1 backup satellite on each of 3 orbits. The services provided will be four positioning services, i.e., open service, public regulated service, commercial service, and Safety of Life (SoL) service, as well as a search and rescue (SAR) service. Four In Orbit Validation (IOV) satellites were launched, 2 in 2011 and 2 in 2012, to test their performance, with the start of Full Operational Capability (FOC) satellites from 2014, and a total of 8 satellites launched by 2015. Of those, 2 of the 8 satellites failed to enter the designated orbit, however recovery plans have been made to examine whether or not they can be used as part of the system. Six satellites are scheduled for launch during 2016, and the start of first-stage service is planned during 2016.

Japan is constructing a regional system, the above-mentioned QZSS, for the purpose of supplementing/augmenting GPS signals by use of an inclined orbit synchronized with the Earth’s rotation. The first satellite, Michibiki, was launched in September 2010 and is now in operation. QZSS will ultimately comprise 4 satellites, including 1 GEO satellite, and is scheduled to begin service in 2018. The Space Strategy Office of the Cabinet Office of Japan is currently developing the 3 satellites and terrestrial system. The schedule for the Basic Plan for Space Policy was revised in January 2015, which specified that the system would be expanded to 7 satellites by around 2023.

India is constructing the regional satellite positioning system IRNSS, which will provide open service and public regulated service as independent positioning services. The system will consist of a total of 7 satellites, including 3 GEO satellites and 4 IGSO satellites. The first satellite in the system was launched on July 1, 2013, with 4 satellites already placed into orbit as of the end of 2015.

Information on the systems of each country was arranged in order to evaluate satellite constellation performance. The number of satellites necessary in order to construct the system (GNSS or RNSS), the number of operational satellites at the present point in time, the condition of implementation and operation of each satellite positioning system, the actual results of provision of stable service since the start of service, the average daily value of PDOP (Position DOP) on the day of analysis, and the average value for the service area calculated from the satellite constellation in operation at the end of 2013 are shown in Table 3-4e.

Table 3-4e Data on satellite constellations

Sector	US	Europe	Russia	Japan	China	India
Number of satellites necessary (GNSS)	27	30	24	-	35	-
Number of satellites necessary (RNSS)	-	-	-	4-7	14*	7
Number of operational satellites	31	12	27	1	14+4**	4
Condition of implementation or operation	Operation	Implementation	Operation	Implementation	Operation	Implementation
Record of stable service***	22	—	4	—	3	—
PDOP****	1.96	—	3.13	—	2.88	13.6

* Expansion of China's Beidou system in steps from RNSS to GNSS is planned; as of the end of 2015, China was providing regional service with a constellation of 14 satellites.

** In addition to the Step 2 regional system, launches have started of Step 3 test satellites, with 4 satellites in operation as of the end of 2015.

*** The number of years of service is counted from the IOC announcement in 1993 for GPS (US), from the restoration of service in 2011 for GLONASS (Russia), and from the announcement of the start of regional service in 2012 for Beidou (China).

**** For GPS and GLONASS, PDOP for a period of 24 hours is an average value for total time-space, calculated at 1 minute intervals at intervals of 2° of latitude and 2° of longitude for the entire globe. The same calculation was made for the service region of Beidou at latitude 55°N to latitude 55°S, longitude 55°E to 180°E, and IRNSS at latitude 5°S to latitude 40°N, longitude 65°E to 100°E.

Table 3-4f shows the results of a total evaluation of satellite constellation performance based on the data in the above Table 3-4e. As a result of the study discussions, the weighting of constellation performance can be considered higher than other evaluation points from the viewpoint of whether it can actually be used as a performance satellite positioning system. For this study, 15 points were assigned to the evaluation of constellations, with the following approaches applied to the assigned points.

Global satellite positioning system completed, and in continuous operation for more than 2 years: 10 points

Regional positioning system completed, and in continuous operation for more than 2 years: 7 points

Global or regional system under development, study of independent positioning system with 4 or more satellites already complete: 5 points

Global or regional system under development: 3 points

Average DPOP across entire service area 6 or less (add 5 points)

Table 3-4f Evaluation of satellite constellation performance

	Max.	US	Europe	Russia	Japan	China	India	Canada
GNSS/RNSS operation	10	10	5	10	3	7	5	0
PDOP	5	5	0	5	0	5	0	0
Evaluation	15	15	5	15	3	12	5	0

(Maximum possible score: 15)

(c) GNSS usage technology (receiver, augmentation technology)

a) GNSS receiver

From the perspective of positioning usage, the use of multiple GNSS is expanding, and instead of just high-end receivers for surveying that are increasingly capable of use with multiple systems, compatibility with GPS+GLONASS+Beidou is also becoming more mainstream as a type of chipset for general consumers.

Chips that are compatible with Europe's Galileo and Japan's quasi-zenith satellites are being released onto the market, which provides positioning usage with a high level of availability, even in urban areas and other environments that make positioning difficult. Chipsets for general consumers are being sold integrated with communication modules in line with the uptake of smartphones, with chips from companies like Qualcomm (US) and Broadcom (US) make up a large ratio of the market. Even chipsets for car navigation, digital cameras or other devices with no integrated smartphone, cellphone or other communication modules, like u-blok (Switzerland) and Mediatek (Taiwan) have secured a significant share of the global market. Japanese chipset manufacturers such as Furuno Electric, JRC Nihon Musen, Sony, and Seiko Epson are aiming to expand their share with greater sensitivity or lower power consumption to suit increased IoT uptake. There was a time when Japanese companies held a large share of the car navigation device market, however the increase in personal navigation devices (PND) around the world have resulted in companies such as Garmin (US) and Tom Tom (Netherlands) gaining market share, although this share is being eroded by smartphone apps due to the increase in number of smartphones being used.

Patents for high-end receivers for surveying that use 2 frequencies were largely owned by American companies leading to American and Canadian companies securing a major portion of the market. Advancements to GNSS systems in each country and the increase in the number of civilian signals available for the public have led to the development of high-end receivers for surveying that can use more than 2 frequencies, which have been released into markets for commercial use in the countries that covered by this comparative study.

Satellite positioning is used daily in a wide range of fields in the world's advanced space development countries that are covered by this comparative study, with products and services already generally commercially available and where popularity is subject to market in the majority of cases. The difference in GNSS usage technology is considered to be minimal, and thus a comparison of technical capability was excluded from the comparative study.

b) GNSS augmentation technology

The important items in GNSS augmentation technology are the SBAS (Satellite Based Augmentation System) and augmentation service for carrier wave phase positioning. Therefore, in the present study, GNSS augmentation technology was evaluated based on those two items.

○ SBAS

SBAS is a technology for enhancing GPS positioning accuracy and reliability by transmission of augmentation signals. Respective countries have implemented and operate SBAS to provide augmentation services which satisfy the requirements provided by the International Civil Aviation Organization (ICAO). The WAAS (Wide Area Augmentation System) in the United States, EGNOS (European GNSS Navigation Overlay Service) in Europe, MSAS (MTSAT Satellite Augmentation System) in Japan, and India's GAGAN are currently operational, with Russia's SDCM and China's Beidou Satellite-Based Augmentation System (BDSBAS) in the system implementation stage. Korea has also started development of its own SBAS system.

It is thought that a technical comparison of the SBAS of each country is possible based on the operational phase of aircraft that currently operate using SBAS. The US system WAAS, Europe's EGNOS, and India's GAGAN provide APV services. The area around Japan is close to the magnetic equator, making the geographical environment for ionosphere compensation more difficult compared to the US and Europe, and thus Japan's MSAS provides enroute and NPA service of a lower level than the systems in the US and Europe. India also suffers from a tough ionosphere environment, however applies ionosphere compensation using a multi-layer model, which received ICAO certification in April 2015. In the case of Russia's SDCM and China's BDSBAS, confirmation has not been completed, and their status is at the "System verification" stage.

○ Augmentation service for carrier wave phase positioning

Service utilizing Precise Point Positioning (PPP) has been developed as an augmentation service for carrier wave phase positioning. In this type of service, the ground system provides network-type real time kinematic (RTK) service, and precise estimation of the satellite orbit and clock are performed in the satellite system. Table 3-4g shows the main items in augmentation service for real-time carrier wave phase positioning.

Table 3-4g Representative examples of carrier wave phase positioning augmentation services

Country	Service provider	Service	Positioning method	Accuracy (RMS)		Service area	Augmentation object systems	Transmission method
				Horizontal	Vertical			
US	NASA	GDGPS	PPP	Up to 10cm		World	GPS GLONASS	TDRS Internet
	Trimble	Centerpoint RTX	PPP-AR	Up to 2cm		World	GPS,GLONASS,QZSS	GEO satellite Internet
Europe	CNES	PPP-Wizard	PPP-AR	Up to 2cm	5cm	World	GPS GLONASS	Internet
	Terrastar	TerrastarD	PPP	5cm	10cm	World	GPS GLONASS	GEO satellite Internet
Japan	SPAC	CMAS	RTK-PPP	3cm	6cm	Japan	GPS	QZSS
	JAXA	MADOCA	PPP	10cm	10cm	East Asia Oceania (QZSS) World	GPS GLONASS QZSS	QZSS Internet

The PPP system has the drawback that time is required for convergence; however, shorter convergence times have been realized by Trimble's Centerpoint RTX service and the CMAS (Centimeter class augmentation signal) of Japan's Satellite Positioning Research and Application Center (SPAC) by ionospheric and tropospheric delay compensation using a network of local reference points. Conversely, however, because a dense reference point network and transmission band are necessary, the service area for reduced initialization time by Centerpoint RTX is limited to part of North America, while that of CMAS is limited to Japan.

Of the above services, CNES, JAXA and SPAC are still in the verification phase and not commercially ready to be used as a constant service.

Table 3-4h shows the results of a comparison of augmentation technologies. For SBAS, 4 points were given to services that provide APV service, 2 points were given to services that provide NPA service, and 1 point was given for systems currently in verification for confirmation. For carrier wave phase augmentation of systems already in service, 4 points were given to countries with service having horizontal accuracy of <5cm, 2 points were given for 5-10cm, and 1 point was given to countries with a service that has completed performance verification but has not yet begun practical service.

Table 3-4h Evaluation of GNSS augmentation technologies

	Max.	US	Europe	Russia	Japan	China	India	Canada
SBAS	4	4	4	1	2	1	4	—
Carrier wave phase Augmentation	4	4	4	—	1	—	—	—
Total	8	8	8	1	3	0	4	0
Evaluation	4	4	4	0.5	1.5	0.5	2	0

(Maximum possible score: 8 ⇒ converted to maximum overall evaluation score: 4, in increments of 0.5)

(d) Summary of positioning

Table 3-4i shows the results of a total evaluation of positioning technologies based on the evaluation results presented above.

Table 3-4i Total evaluation of positioning technologies

Sector	MAX	US	Europe	Russia	Japan	China	India	Canada
SIS-URE	10	10	8	6	8	8	2	2
Constellation	15	15	5	15	3	12	5	0
GNSS augmentation technology	4	4	4	0.5	1.5	0.5	2	0
Total	29	29	17	21.5	12.5	20.5	9	2
Overall evaluation	10	10	6	7. 5	4.5	7	3	0.5

(Maximum possible score: 29 ⇒ converted to maximum overall evaluation score: 10, in increments of 0.5)

(5) Summary of Space applications sector

Table 3-5 (same as Table 3 on P29) shows the results of the total evaluation of the space applications sector based on the 4 areas above.

Table 3-5 Total evaluation of Space applications field

Sector	Max.	US	Europe	Russia	Japan	China	India	Canada
Satellite bus technology	10	10	9.5	5.5	7	5	3.5	1
Satellite broadcasting	10	9	8.5	3	5	3.5	2	3
Earth observation	10	8	8.5	4	6	5.5	4	3
Positioning	10	10	6	7.5	4.5	7	3	0.5
Total	40	37	32.5	20	22.5	21	12.5	7.5
Overall evaluation	30	28	24.5	15	17	16	9.5	5.5

(Maximum possible score: 40 ⇒ converted to maximum overall evaluation score: 30, in increments of 0.5)

4. Space science

◎ Overview of space science

Space science covers many different aspects, which involve: observing astronomical and space physics from outside of the earth's atmosphere in order to research the way that space behaves and its origins; solar system science aimed at studying the origins of the Earth and the solar system, as well as the environment throughout the heliosphere that comes under the sun's influence; space environment utilization science where various experiments are conducted in microgravity and other environments; and space engineering that supports all of this research and opens up new potential in the realm of space. Space science research expands humankind's frontier of knowledge, and is one of the fields of study that is the key to advancing space technology.

Small-scale flying objects (such as sounding rockets and air balloons) are of extreme importance to space science research, and are widely used for groundbreaking research topics and ambitious studies. They have led to the discovery of X-ray objects (Nobel Prize in Physics) and major scientific breakthroughs, however have not been included in this evaluation.

◎ Main accomplishments from 2014 to 2015

In the field of space science, 1 asteroid probe (Japan) was launched in 2014, while in 2015, a total of 7 satellites were launched: 4 magnetosphere observation satellites in tetrahedral formation (US), 2 astronomical observation satellites (China, India), and a gravitational wave detection satellite (ESA). This brings the total launched over 2 years to 8 satellites.

Japan successfully launched the asteroid probe Hayabusa on December 3, 2014, which then successfully used gravity assist on December 3, 2015. Elsewhere, the Venus probe Akatsuki successfully entered into a circular orbit around Venus on December 7, 2015. Akatsuki is Japan's very first asteroid probe.

The US succeeded in inserting the asteroid probe Dawn into circular orbit around the Ceres asteroid in March 2015, while in July 2015, the Pluto space probe New Horizons performed a flyby study of Pluto and its moon Charon to acquire detailed images. This led to the unprecedented discovery of a diverse geographical landscape on Pluto and Charon as well as detailed observation of their atmospheres.

In 2014, Europe successfully landed space probe Rosetta's lander Philae on comet Churyumov-Gerasimenko.

◎ Revised sectors and evaluation standards

The previous evaluation method was revised for this study, with evaluations conducted for each of the following items.

1) Solar system exploration: given the difficulty associated with some object celestial bodies, points were assigned for the technical milestone achieved, including conducting a flyby observation, orbital study, landing and exploration, or recovering samples.

2) Astronomical and space physics observation: a priority was placed on the performance of observation equipment to suit each observation wavelength or application, with points also assigned by taking into consideration the observation method and the orbit that the equipment was inserted.
3) Near earth space, solar wind and solar observation: points were assigned using a similar approach to astronomical and space physics observation.

The main changes from the previous study are as follows.
The first consideration is the quality of technology used (the technical milestone achieved). The mass (quantity) of satellites was not factored in for 1).

For fields 2) and 3), the performance of observation equipment has increased over time, with a large quantity available. Thus the evaluation only covered satellites and space probes used for observations after 2000. (Accordingly, satellites that are currently under development were excluded)
The scope of scientific results is proportional to the technology (equipment specifications) used, however this evaluation is specifically for the technical capability of observation satellites, so the number of published results was excluded from the evaluation.

Using these methods, the evaluation results of the space science sector are shown in Table 4.

Table 4 Evaluation of space science sector (2015)

Sector	Max.	US	Europe	Russia	Japan	China	India	Canada
Solar system exploration	20	19.5	9	9	7.5	4	4	0
Astronomical and space physics observation	20	20	15.5	0.5	10	0	1.5	0
Near earth, sun	20	20	3.5	4	4.5	2	0	0
Total	60	59.5	28	13.5	22	6	5.5	0
Overall Evaluation	20	20	9.5	4.5	7.5	2	2	0

(Maximum possible score: 60 ⇒ converted to maximum overall evaluation score: 20, in increments of 0.5)

In the previous (2013) study (Reference 4), evaluations were conducted based on: (1) Lunar/planetary exploration [1] lunar exploration (number of lunar probes), [2] planetary exploration (number of planetary probes and number of object planets, [3] record of return to Earth, and [4] scientific viewpoint (number of papers published in LPSC); (2) Astronomical observation [1] number of astronomical observation satellites, [2] scientific viewpoint (impact factor on scientific journals); (3) Observation of near-earth space environment [1] number of space environment observation satellites, [2] scientific viewpoint (number of COSPAR meetings held and number of papers presented at COSPAR).

Reference 4: Evaluation of space science sector (2013)

Sector	Max.	US	Europe	Russia	Japan	China	India	Canada
Lunar/planetary exploration	20	20	9	9	8	5	4	2
Astronomical observation	20	16	10	5	8	1	0	1
Observation of near-earth space environment	20	20	15	9	6	5	4	4
Total	60	56	34	23	22	11	8	7
Overall Evaluation	20	19	11	8	7	4	3	2

(Maximum possible score: 60 ⇒ converted to maximum overall evaluation score: 20, in increments of 1)

The evaluation method has been changed which means a direct comparison of 2013 evaluation results is not possible, however the US continues to keep its dominant position even in the field of space science. Europe scored additional points in areas such as astronomical observation, and is increasing its presence in this field. Japan is maintaining a strong position shortly behind Europe. One point to note is the progress that China and India are starting to make in the field of space science.

(1) Solar system exploration

A look back at history shows that solar system exploration began by exploring the moon that orbits the Earth, and moved out to asteroids and comets that approach the Earth, and then other planetary bodies comparatively nearby, such as Mars and Venus. Exploration then expanded further to Mercury, Jupiter and then planets and other small celestial bodies and their moons. Accordingly, the level of difficulty of exploration differs depending on the object celestial body. Even exploration of the same celestial body can be separated into different technical milestones, including conducting a flyby observation, orbital study, landing and exploration, or recovering samples, and the rate at which each country achieves these steps also differs.

While the evaluation items are non-exhaustive, this field is comprised of a wide range of characteristic technologies, including ultra-long distance communications, swing-by, precision orbit control, autonomous navigation, aero-braking, landing and take-off, unmanned mobile exploration (surface, surface layers, underground, airborne), penetration, impactors, thermal limit control (inner planets, outer planets, overnight), electrical propulsion, solar light and solar wind propulsion (solar sails, plasma sails), sample recovery, and atmospheric (re)entry from interplanetary space.

The evaluation results of the solar system exploration field are shown in Table 4-1a.

Table 4-1a: Evaluation of the solar system exploration field

Celestial Body	Max.	US	Europe	Russia	Japan	China	India	Canada
Moon	5	5	3	5	3	4	3	0
Asteroid, comet	5	5	4	2	5	2	0	0
Mars and its moons	4	4	3	3	0	0	3	0
Venus	4	3	3	4	3	0	0	0
Mercury	3	3	1	0	1	0	0	0
Jupiter and its moons	3	3	0	0	0	0	0	0
Saturn and its moons	4	4	0	0	0	0	0	0
Uranus, Neptune	2	2	0	0	0	0	0	0
Trans-Neptunian objects	2	2	0	0	0	0	0	0
Total	32	31	14	14	12	6	6	0
Evaluation	20	19.5	9	9	7.5	4	4	0

(Maximum possible score: 32 ⇒ converted to maximum overall evaluation score: 20, in increments of 0.5)

For the evaluation, 1 point was given to technology under development, 2 points to a successful flyby, 3 points to successful orbital exploration, 4 points to a successful landing and exploration, and 5 points for successfully recovering samples. Joint international missions are common in the space science field, however in general, points have only been assigned to the main country achieving that particular technical milestone.

The space probes covered by the evaluation are shown in Table 4-1b.

Table 4-1b: Key solar system space probes by country

Celestial Body	US	Europe	Russia	Japan	China	India	Canada
Moon	Lunar Prospecter	Smart1	Luna	Kaguya	Chang’e 1	Chandra yaan	—
Asteroid, comet	ISEE-3, Dawn	Giotto Rosetta	Vega	Suisei, Hayabusa	Chang’e 2	—	—
Mars and its moons	Viking, MSL	Mars Express	Mars	Nozomi (failed)	—	Mangal yaan	—
Venus	Mariner, Magellan	Venus Express	Venera	Akatsuki	—	—	—
Mercury	Mariner, Messenger	—	—	—	—	—	—
Jupiter and its moons	Galileo, Juno	—	—	—	—	—	—
Saturn and its moons	Cassini	—	—	—	—	—	—
Uranus, Neptune	Voyager	—	—	—	—	—	—
Trans-Neptunian objects	New Horizons	—	—	—	—	—	—

(2) Astronomical and space physics observation

Astronomical and space physics observation is broadly classified by the observation wavelength or particles, and include γ-rays, X-rays, ultraviolet light, visible light, infrared light, radio waves, and cosmic rays, however categories are required to suit the purpose of research being conducted, including space VLBI observation, solar observation, precision photometry observation of exoplanets, astrometric observation, and gravity wave detection.

While it is difficult to accurately quantify the level of technical milestones achieved with these astronomical observation satellites, there is a base level of performance required for each observation objective. Thus, an evaluation was conducted on the performance of the observation equipment in line with these base performance levels. It must be noted that some observation methods may forgo other areas of base performance to accomplish the required observation method, and the actual observation method may be proportional to the technical capability used. These notes were factored when assigning points. Accordingly, the points for the technology of each satellite was determined as follows. First, technology was categorized for each observation objective. Common base performance items were defined within each category, with a maximum of 3 points assigned to each performance item. The number of base performance items differs with each category, so the sum of points for base performance items was divided by the number of items to determine the average, which was then used as the base performance evaluation score. Next, a score was defined from common observation methods in each category, which was multiplied by the base performance evaluation score to determine the final score. The main points assigned are shown in Table 4-2a.

The satellites and space probes covered by the evaluation are shown in Table 4-2b. Astronomical and space physics missions mounted on the ISS's Exposed Facility has been included in Table 4-2b as they consist of a similar level of performance for evaluation. Points for joint international missions were assigned to the main country leading that mission. These missions were evaluated using Table 4-2a to determine the evaluation results of the astronomical and space physics observation field for each country from the total number of points. The results are shown in Table 4-2c.

Table 4-2a Points assigned for main observation capabilities in the astronomical and space physics observation field

Observation Method Item (multiplication factors common to all categories)						
Orbit	1.2: L2 halo, 1.1: sun orbit, 1.0: Earth orbit					
Observation Mode	1.1: Survey, 1.0: Directional, monitoring					
Basic Performance Evaluation Item (averaged)						
Capability	γ-ray	X-ray	Ultraviolet light	Visible light	Infrared light	Radio wave (CMB)
Spatial resolution	3 : <360" 2 : <3600 1 : ≥3600	3 : <5" 2 : <30 1 : 180 0 : ≥180	3 : <1" 2 : <10 1 : >10	3 : <0.05" 2 : <0.2" 1 : >0.2"	(#)	3 : <360" 2 : <3600 1 : ≥3600
Telescope aperture					3:>100 cm 2 : >50 cm 1 : <50 cm	
Effective detection area	3 : 1000cm^2 2 : ≥100 1 : <100	(imaging system) 3 : 1000cm^2 2 : ≥100 1 : <100 (non-imaging) 3 : ≥10000 2 : ≥1000 1 : <1000	3.0:>100cm^2 2.0 : >10 1.0 : <10			
Observation band		3 : ≥50keV 2 : ≥3keV 1 : <3keV			3: >200um 2 : >22um 1 : <22um	3 : ≥10 band 2 : >5 1 : <5
Spectroscopic performance (λ/⊿λ)	3 : ≥100 2 : ≥10 1 : <10	3 : ≥100 2 : ≥10 1 : <10	3 : ≥10000 2 :≥1000 1 : <1000	3 : ≥10000 2 : ≥1000 1 : <1000	3 : 10000 2 : 1000 1 : 100	
Others					(primary mirror temperature) 3 : <6K 2 : <10K 1 : >20K	(number of simultaneous observation directions) 3 : >100 2 : >10 1 : <10

(#) The spatial resolution of infrared light observation depends on the wavelength and telescope aperture, so the telescope aperture has been used as the evaluation item instead of spatial resolution.

Table 4-2b: Astronomical and space physics observation satellites by country (used for observation after 2000)

Sector	US	Europe	Russia	Japan	India
Radio wave CMB	COBE,WMAP	Planck			
Radio wave VLBI			Specktr-R	Haruka	
Infrared light observation	Spitzer, WISE	ISO, Herschel		Akari	
Visible	HST				
Astrometric		GAIA			
Exoplanet	Kepler	COROT			
Ultraviolet light observation	EUVE, FUSE, GALEX			Hisaki	
X-ray observation (<1MeV)	RXTE, Chandra, SWIFT, Nu-Star	BeppoSax, XMM-Newton, INTEGRAL		Asuka, Suzaku MAXI/ISS,	AstroSat
Gamma-ray observation (>1MeV)	Fermi	AGILE			
Cosmic ray electron component	AMS/ISS	PAMELA		CALET/ISS	

Table 4-2c: Evaluation of the astronomical and space physics observation field

Category	US	Europe	Russia	Japan	India
Radio wave CMB	3.08	2.48	0	0	0
Radio wave VLBI	0	0	0.50	1.00	0
Infrared light observation	3.58	5.45	0	2.20	0
Visible	3	0	0	0	0
Astrometric	0	3.30	0	0	0
Exoplanet	1.21	1.10	0	0	0
Ultraviolet light observation	5.13	0	0	1.00	0
X-ray observation (<1MeV)	7.75	6.00	0	7.75	2.00
Gamma-ray observation (>1MeV)	2.57	1.83	0	0	0
Cosmic ray electron component	2.00	1.50	0	2.00	0
Total	28.32	21.66	0.50	13.95	2.00
Evaluation	20	15.5	0.5	10	1.5

(Maximum possible score: 20. Converted in 0.5 increments with US as 20)

China and Canada received 0 points as they have no applicable satellites.

(3) Near earth space, solar wind and solar observation

Multiplication factors and additional points were also defined for the evaluation method and performance items for near earth space, solar wind and solar observation as shown in Table 4-3a, and an evaluation was conducted in accordance with formula (1). The satellites and space probes covered by the evaluation are shown in Table 4-3b, and the evaluation results are shown in Table 4-3c.

Table 4-3a Points assigned for observation capabilities in the near earth space, solar wind and solar observation field

Observation Method Item (multiplication factors common to all categories)					
Orbit	1.2: Special orbit, 1.0: Earth orbit/L1				
Basic Performance Evaluation Item (averaged)					
Plasma Measurement	Energy Range	Energy Resolution	Temporal Resolution	Ion species Resolution	Simultaneous Multipoint
	3 : eV-GeV 2 : eV-100MeV 1 : Smaller	3 : <10% 2 : < 20% 1 : ≥20%	3 : < 0,1 s 2 : <1 1 : <10 0 : ≥10	3 : m/dm≥10 2 : ≥1 1 : <1 0 : 0	4 : ≥4" 3 : 3 2 : 2 1 : 1
Magnetic Field Measurement	Magnetic Field Resolution	Temporal Resolution			
	3 : ≥20bit 2 : <20bit, & <10 pT 1 : <20bit & ≥10 pT	3 : ≥128 S/s 2 : ≥16 S/s, 1 : <16 S/s			
Solar observation	Wavelength Range	Spatial Resolution	Wavelength Resolution		
	3 : all infrared, visible, ultraviolet, X, gamma rays 2 : 3 of the above 1 : Less than 2 of the above	3 : <1” 2 : < 2 1 : ≥2	3 : ≥1000 2 : ≥100 1 : <100		

Table 4-3b Near earth space, solar wind and solar observation satellites and space probes by country (used for observation after 2000)

Sector	US	Europe	Russia	Japan	China
Cosmic space plasma	THEMIS, Van Allen Probe, MMS	Cluster		Geotail, Akebono, Reimei, Kaguya	Double Star (Tan Ce)
Solar wind	Ulysses, WIND, ACE, Genesis, DSCOVR	SOHO			
Sun	STEREO, SDO		Koronas-F, Koronas-Foton	Hinode	

Table 4-3c Evaluation of the near earth space, solar wind and solar observation field

Category	US	Europe	Russia	Japan	China	India	Canada
Cosmic space plasma	7.43	2.29	0	1.86	2.00	0	0
Solar wind	9.03	1.29	0	0	0	0	0
Sun	3.53	0	4.00	2.67	0	0	0
Total	19.99	3.57	4.00	4.52	2.00	0	0
Evaluation	20	3.5	4	4.5	2	0	0

(Maximum possible score: 20, in increments of 0.5)

The evaluation results of the near earth space observation field are shown in Table 4-3c. For the evaluation, 1 point was given to satellites under development, 2 points to small-scale satellites, 3 points to medium-scale satellites, and 5 points to large-scale satellites. Large-, medium- and small-scale satellites were categorized by the respective weight classes of 3000kg or more, 500-3000kg, and less than 500kg. Joint international missions, however in general, points have only been assigned to the main country achieving that particular technical milestone.

(4) Summary of space science sector

Table 4-4 (same as Table 4 on P67) shows the summary of these 3 fields, and the overall space science evaluation.

The maximum score for each of the 3 fields indicates the weighting of each field, which shows a close correlation with the number of satellites and space probes covered by the evaluation.

Table 4-4 Evaluation of space science sector (2015)

Sector	Max.	US	Europe	Russia	Japan	China	India	Canada
Solar system Exploration	20	19.5	9	9	7.5	4	4	0
Astronomical and space physics observation	20	20	15.5	0.5	10	0	1.5	0
Near earth, sun	20	20	3.5	4	4.5	2	0	0
Total	60	59.5	28	13.5	22	6	5.5	0
Overall Evaluation	20	20	9.5	4.5	7.5	2	2	0

(Maximum possible score: 60 ⇒ converted to maximum overall evaluation score: 20, in increments of 0.5)

5. Manned space activities

Manned space activities in recent years mainly involve long-term stays in space at the International Space Station (ISS). The 2015 evaluation places a greater weighting on the technical capability related to manned long-term stay in space with a view to future lunar/planetary exploration. The evaluation results of the manned space activity sector are shown in Table 5.

When compared to the previous results (Reference 5), there are no major changes in order, however there is now a smaller gap between the US, which has experience with the Apollo program more than 40 years ago, and Russia, which is currently in charge of manned transportation to the ISS. The evaluation score has increased for China, Japan and Europe, however China maintains its 3rd position with its operating history of manned spacecraft. When China begins construction of its own space station, the gap between Japan and Europe is expected to grow even further. The Japanese Experimental Module Kibo features a proprietary robot arm and airlock, and with the increase in the number of external missions using the robot arm, the technical capability of Japan was evaluated higher than that of Europe. India received points for its small-scale retrievable satellite, and its evaluation score increased. Almost no revisions have been for Canada since the previous evaluation.

Table 5 Evaluation results of manned space activity sector

Sector	Max.	US	Europe	Russia	Japan	China	India	Canada
Manned spacecraft operations technology	8	7	0	7	0	4	0	0
Astronaut operations technology	10	10	7	10	7	7	2	4
Manned long-term stay in space technology	14	14	7	12	9	9	1	2
Space environment utilization experimental technology	4	4	4	4	4	2	2	2
Manned space exploration Technology	4	3	2	1	1	1	1	0
Total	40	38	20	34	21	23	6	8
Overall evaluation	20	19	10	17	10.5	11.5	3	4

(Maximum possible score: 40 ⇒ converted to maximum overall evaluation score: 20, in increments of 0.5)

Reference 5 Results of Previous Study (2013)

Sector	Max.	US	Europe	Russia	Japan	China	India	Canada
Manned spacecraft and operations control technology	15	15	4	13	4	11	0	0
Manned space stay Technology	14	14	11	14	10	11	1	3
Manned space activity support technology	6	5	2	3	3	3	0	3
Space environment experiment technology	6	6	5	6	5	0	0	2
Manned space exploration technology	12	12	1	3	1	1	1	1
Total	53	52	23	39	23	26	2	9
Overall evaluation		20	9	15	9	10	1	3

(Maximum possible score: 53 ⇒ converted to maximum overall evaluation score: 20, in increments of 1)

Source: "G-TeC　A Comparative Study on Space Technology in the World" (March 2013)

◎ **Summary of manned space activities in each country**

On November 2, 2015, the ISS celebrated 15 years of hosting long-term stays by astronauts. In that time, more than 221 astronauts from 18 countries have visited the ISS, and conducted in excess of 1760 experiments. The ISS is a symbol of international cooperation and peace, with astronauts and ground staff from different academic backgrounds and cultures respecting one another and cooperating with its operation.

A record of manned activities conducted over these 2 years is summarized in Reference 5-1.

Reference 5-1 record of manned activities 2014-2015

	US	Europe	Russia	Japan	China	India	Canada
Record of manned spacecraft flights	0	0	8	0	0	0	0
Number of Astronaut Flights	9	4	14	2	0	0	0
Number of days in Space	1,341 days	391 days	2,035 days	274 days	0 days	0 days	0 days
Record of cargo Resupply	7 successes 2 failures	1 success	8 successes 1 failure	1 success	0	0	0

Transportation of crew to the ISS is covered solely by the Russian manned spacecraft Soyuz, which transports astronauts at a frequency of 4 times a year. Commercial passenger transportation is being developed in the United States by private companies, with potential candidates narrowed down to Boeing's CST-100 and SpaceX's Dragon V2, which are aiming for a 2017 launch.

Operation of the European Space Agency's 5th came to an end as the cargo transport vehicle to the ISS, with Russia's Progress, America's Dragon and Cygnus, and Japan's Kounotori currently in operation. Kounotori transports large equipment that cannot be carried by the other transport vehicles, and all resupply missions to date have been successful, earning it high international acclaim. While other transport vehicles failed their shipments one after another from 2014 to 2015, Kounotori 5 was launched in August 2015 and caught by astronaut Yui, who is on a long-term stay at the ISS, highlighting the success of the vital cargo required for ISS operations.

China is planning to launch the manned spacecraft Shenzhou, cargo transport vehicle Tianzhou and experimental modules Tianhe, Wengtian and Mengtian, in the leadup to the construction of its space station Tiangong.

◎ Revised sectors and evaluation standards

Current manned space activities focus on long-term stays in a low earth orbit, and with lunar/planetary exploration followed by exploration of Mars planned in the future, the evaluation method and evaluation standards have been revised. Specifically, evaluation was classified into manned spacecraft operations technology, and manned stay in space technology, with manned stay in space technology being changed to manned long-term stay in space technology. Space environment utilization experimental technology also consists of two components, experimental equipment development technology, and space environment utilization experimental records, while manned space exploration technology consists of lunar/planetary exploration, and Mars exploration technology. The evaluation standards were revised with a view to ongoing use for the next 10 years.

◎ Future developments

With the exception of ESA, the countries participating in the ISS program decided to extend ISS operations to 2024, with ESA expected to make a decision at the 2016 Council meeting. China is aiming to begin construction of its new space station Tiangong after 2018, with completion slated for 2022.

In January 2014, the cabinet ministers, heads space agencies and other members of 35 countries, regions and organizations held the International Space Exploration Forum (ISEF) to discuss the significance and importance of international space exploration. It was the first time a number of developing countries decided to participate in space exploration, demonstrating the value of space activities for driving sustainable growth. Using the experience of projects such as the ISS, the forum highlighted the importance of discussing an international framework and common principles for the future cooperation of space exploration. The second ISEF is planned to be held in Japan in 2017.

◎ **Emerging country trends**

The United Arab Emirates (UAE) established the space agency UAESA in 2015, demonstrating the desire to participate in manned space activities with a view to exploration of Mars through international cooperation.

(1) Manned spacecraft operations technology

A comparison of the technical capability of manned spacecraft that are required for conducting manned space activities was evaluated with two items: record of flights of manned spacecraft, and the number of flights. As of 2015, only three countries have a track record with manned spacecraft, Russia, the United States and China. The limited number of available spacecraft also indicated that it was too early to conduct detailed technical comparisons of each type, so only a quantitative comparison was conducted based on flight records.

(a) Manned spacecraft technology

It has been 54 years since the former Soviet Union launched the first manned spacecraft in the world, yet there are few countries with a flight record of manned spacecraft. The United States succeeded in sending man to the moon with the Apollo program, however the last manned spacecraft to the land on the moon was in 1972. Meanwhile, there is an extremely low probability of humans landing on Mars within the next decade. Accordingly, 3 points were given to countries with a flight record of manned spacecraft, 1 points for a record of test flights of manned spacecraft, and 0 points if there was no record. An additional point was added for manned flight to the moon.

The United States is the only country with such an achievement, and was given 4 points. Russia and China have records of flying manned spacecraft in a circular orbit around the Earth, and were each given 3 points. Other countries have no test flights of manned spacecraft, and received 0 points.

(b) Number of manned spacecraft flights

Manned spacecraft require advanced system technology. They also differ largely to other spacecraft in that they require added safety for their human crew. Maintaining regular flights of manned spacecraft requires a significant level of technical capability to achieve, and it is no easy task to resume flights after an accident that results in death. Thus, in addition to flight records, points were assigned based on the number of flights, with 3 points given for more than 30 flights in the last 10 years (2006-2015), 2 points for 15-29 flights, 1 point for 1-4 flights, and 0 points for no flights. An additional point was added for records of more than 100 flights in total.

Russia has launched the manned spacecraft Soyuz 34 times in the last decade, and has more than 100 flights in total, so was given 4 points. The US has launched the space shuttle 21 times in the last decade, and has more than 100 flights in total, so was given 3 points. China has launched the Shenzhou 3 times in the last decade, and has 5 flights in total, so was given 1 point. Other countries have no flights, and were given 0 points.

(c) Summary of manned spacecraft operations technology

Table 5-1 shows the results of the evaluation of manned spacecraft operations technology based on the results of the individual evaluations presented above.

Table 5-1 Evaluation of manned spacecraft operations technology

Sector	Max.	US	Europe	Russia	Japan	China	India	Canada
Manned spacecraft technology	4	4	0	3	0	3	0	0
Number of flights of manned spacecraft	4	3	0	4	0	1	0	0
Evaluation		7	0	7	0	4	0	0

(Maximum possible score: 8)

(2)Astronaut operations technology

Ever since space stations such as Mir and the ISS became operational, even countries without their own manned spacecraft have provided education and training for astronauts to take part in manned space activities. Thus the existence of astronaut training facilities or training technology is one index that can be used to evaluate a country's manned space technology. The flight records of astronauts is also an index for comparing the technical capability of manned space activities similarly to the flight records of manned spacecraft, so the number of astronauts with experience in space flight and total number of days spent in space was used as the index. Activities conducted outside of space stations broadens the scope of manned space activities, and is one index linked to the technology of future manned space exploration.

(a)Astronaut training technology

1 point was given for training facilities or training technology for astronauts, and 0 points if no such training was available. The United States and Russia have been training astronauts from longer than 50 years ago, and even today have the facilities and technology solely for training astronauts from other countries, so they were both given 1 point. While China imports much of its technology from Russia, it has a record of its own manned space flight, so was given 1 point. Japan and Europe provide experimental modules to the ISS, and each have training facilities for those experimental modules where they also train astronauts from other countries, so they were both given 1 point. Europe also uses caves as part of training for team-building. Canada provides the ISS with robot arms, and has training facilities for using the robot arms for experiments, however this was included in the evaluation for robotics technology, an item in (3) Manned long-term stay in space technology. Training for astronaut is reliant on NASA, so was given 0 points. India does not have any training facilities or training technology, so was given 0 points.

(b) Number of astronaut flights

It has been more than 50 years since Yuri Gagarin became the first human to fly in space in 1961, and in that time more than 500 people have experienced space flight. A drastic increase in the number of people who will experience a short period of space flight is expected in the near future a sub-orbital space flight becomes a reality. Meanwhile, a steady increase in the number of flights orbiting the Earth is also predicted, so 4 points were given if a country has sent 100 or more astronauts into flight orbiting the Earth, 3 points for 50-99 astronauts, 2 points for 10-49 astronauts, 1 point for 1-9 astronauts, and 0 points for no astronauts.

The US has sent 334 astronauts, and Russia 119 when including the former Soviet Union, so both were given 4 points. Europe has sent 46, Japan and China have sent 10 each, so they were given 2 points each. Canada has sent 9 and India 1, so were given 1 point.

(c) Number of days in space

All manned space activities conducted in 2015 were ISS missions, and it has been 15 years since long-stays at the ISS began in 2000. Separate to Russia and the US with more than 10,000 days in space, countries with more than 1,000 days in space in total are deemed have a sufficient track record and technical capability with manned space activity and were given the maximum of 3 points, 2 points for 100-999 days, 1 point for 1-99 days, and 0 points for less than 1 day.

The US has more than 17,000 days in space, and was given 3 points. Russia also has more than 17,000 days in space and was given 3 points, and when combined with the 8,000 days of the former Soviet Union, the total exceeds 25,000 days. Europe has more than 2,300 days in total, led by Germany with 659 days, Italy with 627 days and France with 432 days, and was given 3 points. Japan exceeded 1,000 days in space in 2015 while astronaut Yui was on his long-stay, and was given 3 points for 1071 days in total. Canada was given 2 points for 506 days, and China was also given 2 points for 100 days and 19 hours. India has 7 days, and was given 1 point.

(d) Extravehicular activities of astronauts

As of the end of 2015, 213 astronauts had conducted 717 e xtravehicular activities in total. 1 point was given if astronauts had a record of external activities, and 0 points if no activities were conducted. An additional point was given for a record of developing spacesuits.

The United States has a record of 421 external activities, and also develops spacesuits so was given 2 points. Russia conducted 262 external activities when including the former Soviet Union, and also develops spacesuits, so was given 2 points. China has conducted one external activity with two astronauts, one of whom was wearing a Russian spacesuit, and the other a Chinese spacesuit, so was given 2 points. With European astronauts, France, Germany and Sweden all conducted 5 external activities, Italy 2, and Switzerland 1, for a total of 18 external activities, so was given 1 point. Japan has conducted 8 external activities, and Canada 6, so were given 1 point each. India has 0 activities, and was given 0 points.

(e) Summary of astronaut operations technology

Table 5-2 shows the results of the evaluation of astronaut operations technology based on the results of the individual evaluations presented above.

Table 5-2 Evaluation of astronaut operations technology

Sector	Max.	US	Europe	Russia	Japan	China	India	Canada
Astronaut training technology	1	1	1	1	1	1	0	0
Number of astronaut flights	4	4	2	4	2	2	1	1
Number of days in space	3	3	3	3	3	2	1	2
Extravehicular activities of astronauts	2	2	1	2	1	2	0	1
Evaluation		10	7	10	7	7	2	4

(Maximum possible score: 10)

(3)Manned long-term stay in space technology

The state of technology required for manned space facilities that allow long-term stay in space were evaluated based on records of space flight and the technology used, from the viewpoint of system integration technologies, manned module technologies, life/environment support technologies, sanitation/health management technologies, cargo resupply technologies, cargo recovery technologies, and robotics technologies.

(a) System integration technologies

System integration technologies refer to technology that integrates the various technologies required for manned space facilities and allows them to function as a single system. Countries that have a record of operating manned space stay facilities without the cooperation of other countries were deemed to already have this technology, and were given 2 points. Countries without their own operating records, but with a record of operating the technology and resources of other countries were given 1 point.

The United States, Russia and China have a record of operating their own manned space stay facilities, and were all given 2 points. Europe and Japan operate the Columbus and Kibo modules with resources such as power supplied by the US module under the ISS plan, and were both given 1 point.

(b) Manned module technologies

Countries with a long operating record and that would be considered as having a sufficient level of technology were given 2 points, however countries with a short operating record or an insufficient level of technology were given 1 point.

The United States, Europe, Russia, and Japan supply manned modules for the ISS, and have operated them for a long period of time. The United States and Russia provide the core bus components of the ISS, and also have an operating record for manned modules that exceeds 10 years, (Unity and Zarya were launched in 1998), and were both given 2 points. While Europe and Japan have operated modules for a long period of around 8 years (Columbus, the Japanese experimental module Kibo was launched in 2008), they both rely on the main ISS modules for core functionality, and also use core functional components for docking/berthing ports and hatches, so were given 1 point each. China launched Tiangong 1 in 2011. The most recent time that Tiangong 1 was used as a manned module was in 2013 when docking with Shenzhou 10, and while its 2-years of operation after being launch may not be considered very long, the manned module is thought to use Chinese technology, so was given 1 point.

(c) Life/environment support technologies

Countries with a record of launching life/environment support equipment, and applied recycling-based life/environment support technologies for manned programs were given 2 points, whereas records of using expendable technologies were given 1 point.

The United States and Russia utilize water recycling technologies as part of environmental control systems, and while the technology used to recycle carbon dioxide in exhaled air to oxygen for breathing is not a fully recirculating system, a recycling process is used, so were given 2 points. Europe and Japan operate manned modules on the ISS and their environmental control systems have maintained a long operating record, however expendable technologies are used in certain limited areas such as air recirculation and parts of the heating control, so they were give 1 point each. China's Tiangong 1 and Shenzhou are thought to use expendable technologies for the life/environment support systems. Information and scarce and it is difficult to provide an accurate evaluation, however the systems are thought to be technologies developed in China, so 1 point has been given.

(d)Sanitation/health management technologies

Sanitation/health management includes the management of food, toilet, bacteria and poisons, as well as health management of astronauts before and after a flight, and medical technology while in orbit. The United States and Russia are deemed to have a sufficient track record, and have been given 2 points. Europe and Japan have a sufficient track record with food and health management of astronauts, however do not have an operating record of toilets, galleys or other flight hardware, so have been given 1 point each. China has an operating record for its short mission, however has no operating record for a long-term manned stay in space, and has been given 1 point.

(e) Cargo resupply technologies

Cargo resupplies that are required to maintain long-term manned space activities were evaluated on the development and flights of cargo transport vehicles from the ground to the manned stay facilities. Countries that have launched resupply flights to the ISS and the manned stay facilities of other countries are the US (space shuttle, Dragon, Cygnus), Europe (ATV), Russia (Soyuz), Japan (Kounotori) and China (Shenzhou), and were all given 2 points each.

(f) Cargo recovery technologies

Countries with a record of operating the technology for recovering test samples or replacement equipment from space were given 2 points, and were given 1 point if their records or technology level was insufficient.

The United States, Russia and China have a record of recovering cargo and are thought to have the technical capability to do so, and were given 2 points each. Other countries with a record of flight reentry are Europe, Japan and India, and while their operating record and technology level may be different as outlined below, they were all given 1 point each. Europe has not yet completed its return sample that is planned with Rosetta, however have an operating record of guided reentry flight control with the Atmospheric Reentry Demonstrator (ARD) and Intermediate eXperimental Vehicle (IXV). Japan has an operating record of samples returned via Hayabusa and various other reentry test rockets, however these were under ballistic flight conditions that are not considered sufficient for applications requiring the recovery of biological samples. India has only conducted a demonstration flight under ballistic flight conditions.

(g) Robotics technologies

Countries with a long operating record were given 2 points, however countries with a short operating record or an insufficient level of technology were given 1 point.

The operating record of robotics technologies on board the ISS was used to evaluate the long-term operating record. Canada supplies the ISS with the servicing robot arms Canadarm2 and Dexter. Canadarm2 has been operating well for almost 15 years, and was given 2 points. Japan has also been operating its robot arm installed in the Japanese experimental module Kibo for a long period of just under 8 years, and was also give 2 points. The United States does not have a robot arm operating on the ISS, however has a long operating record of the Mobile Base System, other system components of the robot arm on the Mars rover Curiosity, and research and development into the humanoid Robonaut, and is considered to have sufficient technical capability and was given 2 points. Other countries that are thought to be advancing their research and development includes Europe with its European Robot Arm (ERA), Russia with its humanoid SAR-401, and China with the humanoid robot and space arms that it has published, however their operating record could not be verified, so 0 points were given.

(h) Summary of manned long-term stay in space technology

Table 5-3 shows the results of the evaluation of manned long-term stay in space technology based on the results of the individual evaluations presented above.

Table 5-3 Evaluation of manned long-term stay in space technology

Sector	Max.	US	Europe	Russia	Japan	China	India	Canada
System integration technologies	2	2	1	2	1	2	0	0
Manned module technologies	2	2	1	2	1	1	0	0
Life/environment support technologies	2	2	1	2	1	1	0	0
Sanitation/health management technologies	2	2	1	2	1	1	0	0
Cargo resupply technologies	2	2	2	2	2	2	0	0
Cargo recovery technologies	2	2	1	2	1	2	1	0
Robotics technologies	2	2	0	0	2	0	0	2
Evaluation		14	7	12	9	9	1	2

(Maximum possible score: 14)

(4)Space environment utilization experimental technology

Utilization of the space environment is one of the main objectives of manned space activities. Accordingly, a comparative evaluation of the level of technology was conducted within the manned space activity sector. Until the previous study, the level of technology was evaluated based on experiments in space medicine, life sciences, and microgravity science as well as classification based on the objective of those experiments. As the objective of experiments is likely to change moving forward, this time an evaluation was conducted based on the experimental records as well as the hardware technologies developed for experimental equipment, regardless of the objective of experiments.

Countries with operating records of both space environment utilization experimental records and experimental equipment development technology were given 2 points, with 0 points given if no operating records were available. Note that 1 point was subtracted if some operating records for technology were available but there was a large discrepancy in operating records when compared with other countries.

(a) Space environment utilization experimental records

The former Soviet Union and the United States have conducted space environment utilization experiments dating back to the 1970s with the manned spacecraft Salyut and Skylab, through to today on the International Space Station, so were given 2 points. Europe and Japan have also conducted ongoing space environment utilization experiments ever since the early 1990s with Eureka and FMPT, so were given 2 points. Canada used the US space shuttle and is a member nation of the ISS and has been conducting experiments on space stations, however its operating record lags behind the US, Europe, Russia and Japan, so was given 1 point. China began space environment experiments from around 2000 using Shenzhou, however only has a minimal operating record, so was given 1 point. India launched a small-scale retrievable satellite in 2007 and 2014 to conduct space environment utilization experiments, however only has a minimal operating record, so was given 1 point.

(2) Experimental equipment development technology

Countries with an operating record for space environment utilization experiments generally develop their own experiment equipment. Countries with a long operating record also develop experiment equipment in a wide range of fields, covering life sciences to materials. Accordingly, 2 points were given to US, Europe, Russia and Japan, and 1 point to China, India and Canada for experimental equipment development technology. India's second retrievable satellite included a payload of Japanese life sciences experiment equipment, while China's Shenzhou 8 included Chinese and German life sciences experiment equipment.

(c) Summary of space environment utilization experimental technology

Table 5-4 shows the results of the evaluation of space environment utilization experimental technology based on the results of the individual evaluations presented above.

Table 5-4 Evaluation of space environment utilization experimental technology

Sector	Max.	US	Europe	Russia	Japan	China	India	Canada
Space environment utilization experimental records	2	2	2	2	2	1	1	1
Experimental equipment development technology	2	2	2	2	2	1	1	1
Evaluation		4	4	4	4	2	2	2

(Maximum possible score: 4)

(5)Manned space exploration technology

(a) Lunar/planetary exploration technology

Countries with an operating record of manned space exploration on the moon or asteroids were given 2 points, and those with operating records of unmanned missions that could lead to manned space exploration plans were given 1 point, with 0 points given if no operating records were available.

Only the United States, Russia and China (based on the operating country, rather than the nationality of the astronaut) have an operating record of manned flight beyond the Karman Line (altitude of 100 kilometers). Of those, Russian and Chinese activities are limited to those conducted on space stations, with only the United States with an operating record of manned exploration on the moon.

Japan has an operating record of unmanned missions that could lead to manned space exploration plans of the moon and asteroids. Japan’s Hiten and Okina probes were sent to crash into the moon, Kagura performed observations of the moon, and Hayabusa returned samples that it had retrieved from the asteroid Itokawa. Hayabusa 2, the successor to Hayabusa, was launched in 2014, while the Venus exploration satellite Akatsuki that was launched in 2010 was successfully reinserted into orbit around Venus in 2015. In addition to the United States and Russia which have a long operating record of unmanned probes and soft landings on the moon surface, Europe has operated SMART-1, which was sent to crash into the moon. China’s Chang’e 3 made that country the third to successfully complete a soft landing on the moon’s surface.

(b) Mars exploration technology

Countries with an operating record of manned space exploration on Mars were given 2 points, and those with operating records of unmanned missions that could lead to manned space exploration plans were given 1 point, with 0 points given if no operating records were available.

Japan launched the Mars probe Nozomi in 1998, which approached Mars at around 1,000 km, however was eventually terminated before entering Mars orbit. In the United States, the Obama administration announced plans for a manned exploration of Mars by mid-2030, which has led to a sudden increase in technical development. Russia has been exploring Mars since it was the former Soviet Union, however does not have any examples of a fully successful mission. Europe launched the Mars Express in 2003, and Rosetta that was launched in 2004 passed by Mars in 2007. China launched Yinghuo 1 on board a Russian Mars exploration probe, however probe failed to enter the orbit to depart Earth for Mars, and eventually crashed to the ground. India's Mars Orbiter Mission launched in 2014 was the first successful entry of a probe from Asia into Mars orbit.

(c) Summary of manned space exploration activities

Table 5-5 shows the results of the evaluation of manned space exploration activities based on the individual evaluations presented above.

Table 5-5 Evaluation of manned space exploration technology

Sector	Max.	US	Europe	Russia	Japan	China	India	Canada
Lunar/planetary exploration technology	2	2	1	1	1	1	0	0
Mars exploration technology	2	1	1	0	0	0	1	0
Evaluation		3	2	1	1	1	1	0

(Maximum possible score: 4)

(6) Summary of manned space activity sector

Table 5-6 (same as Table 5 on P89) shows the results of a total evaluation of the manned space activity sector based on the evaluations presented above.

Table 5-6 Total evaluation of manned space activity sector

Sector	Max.	US	Europe	Russia	Japan	China	India	Canada
Manned spacecraft operations technology	8	7	0	7	0	4	0	0
Astronaut operations technology	10	10	7	10	7	7	2	4
Manned long-term stay in space technology	14	14	7	12	9	9	1	2
Space environment utilization experimental technology	4	4	4	4	4	2	2	2
Manned space exploration technology	4	3	2	1	1	1	1	0
Total	40	38	20	34	21	23	6	8
Overall evaluation		19	10	17	10.5	11.5	3	4

(Maximum possible score: 40 ⇒ converted to maximum overall evaluation score: 20, in increments of 0.5)

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