A Comparative Study on Space Technology in the World（2013）

March 2014

Japan Science and Technology Agency (JST)

Center for Research and Development Strategy（CRDS）

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 second G-TeC study of space technology, following a previous study published in November 2011.

This study/analysis is based on trends in space development in various countries and regions up to the end of December 2013. More than 2 years have passed since the previous study, and there have been considerable changes in space development in the respective countries; for example, Russia, China, and India have all made remarkable progress in the field of GPS, and China's activities in manned space flight and lunar exploration have attracted worldwide attention. In order to investigate and analyze these changes and compare the most recent technologies, a "Committee for Comparative Study on Space Technology in the World" was established. Mr. Shigeru Aoe, who is a former Chairman of the Space Activities Commission (SAC), Ministry of Education, Culture, Sports, Science and Technology (MEXT) and also chaired the previous study commission, was again asked to serve as Chairman. Experts from space development organizations, space industries, and research organizations in the several fields which comprise space technology participated as committee members.

Due to the nature of the subject, some portions of space technology development are defense-related, and defense-related technologies are frequently confidential. Accordingly, I would like to note that this study does not describe defense-related technologies, with the exception of those which were developed assuming common use as consumer technologies and have been publicly disclosed. 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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Japan Science and Technology Agency (JST)
Center for Research and Development Strategy (CRDS)
Yukihide Hayashi, Principal Fellow
(In charge of Overseas Trends Unit)

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1. Results of Comprehensive evaluation

First, Table 1-1a is a summary of comprehensive evaluation of each sector.

In comparison with the previous results (Table 1-1b), there is no change in the No. 1 position, which is held by the United States. Although Europe and Russia were ranked No.2 in the previous study, in the present study, Europe is ranked No. 2 and Russia is No. 3. This reflects that Europe marks up the scores of space transportation and science sectors and Russia degrades the score in the transportation sector due to recent launch failures, etc. In the previous study, there was a significant difference between No. 3 Japan and No. 4 China; although the rankings of the two countries have not changed, the difference has been decreased. This is attributed to improved scores for China in the transportation, space applications, and science sectors due to progress in GPS, lunar exploration, etc. No. 6 India and No. 7 Canada have almost the same rating as previous ones.

Table 1-1a Comparative study of space technology: Summary of evaluation results

Sector	Max.	US	Europe	Russia	Japan	China	India	Canada
Space transportation System	30	27	25	25	18	22	11	0
Space Apprications	30	29	25	12	19	12	8	5
Space science	20	19	11	8	7	4	3	2
Manned space activities	20	20	9	15	9	10	1	3
Total	100	95	70	60	53	48	23	10
Rank		1	2	3	4	5	6	7

(Maximum possible score: 100 points)

Table 1-1b Results of previous study (prepared Nov. 2011)

Sector	Max.	US	Europe	Russia	Japan	China	India	Canada
Space transportation System	30	28	23	26	18	21	11	0
Space Apprications	30	28	23	14	18	11	8	7
Space science	20	19	10	8	7	2	2	2
Manned space activities	20	20	9	17	10	10	1	3
Total	100	95	65	65	53	44	22	12
Rank		1	2	2	4	5	6	7

(Maximum possible score: 100) Source: A Comparative Study on Space Technology in the World"(Nov. 2011).

The evaluation items, evaluation criteria, and evaluation results for each sector in the present evaluation are described in detail in the following chapters.

2. Space Transportation Systems Sector

Space transportation systems (STS) comprise launch vehicles, launch complexes, etc. and function as 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 STS 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.

(1) Number of launches 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 2013. The ranking of the countries by number of total launches is Russia > US > Europe > China > Japan > India. The other countries which have capabilities of launching satellites into orbit are Israel (8), Iran (5), and Korea (1).

China is rapidly closing the gap with Europe, and may overtake Europe and become the No. 3 country after 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. 2013)

Category	US	Europe	Russia*	Japan	China	India	Others	World total
Number of launches	1566	236	3159	89	195	39	14	5298
Number of launch failures	141	13	206	8	13	10	4	395
Launch success rate	91.0	94.5	93.5	91.0	93.3	74.4	71.4	92.5

* 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 these data mainly represent the launch performance of vehicles now in service from around the start of operation, and do not consider 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. 2004 to end of Dec. 2013)

	US	Europe	Russia	Japan	China	India	Canada
Number of launches	166	62	300	23	114	22	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. 2004 to end of Dec. 2013)

	US	Europe	Russia	Japan	China	India	Canada
Number of launch failures	3	0	18	0	3	3	0
Launch success rate	98.2%	100%	94.0%	100%	97.4%	86.4%	0
Reliability evaluation	5	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

Evaluation item	US	Europe	Russia	Japan	China	India	Canada
Number of launches	5	5	5	3	5	3	0
Reliability	5	5	3	5	4	1	0
Evaluation (combined score)	**10**	**10**	**8**	**8**	**9**	**4**	**0**

(Maximum possible score: 10)

There were three launch failures in 2013. In January, Sea Launch failed in the launch of an Intelsat satellite with a Zenit 3SL vehicle; in July, Russia failed in the launch of 3 GLOSNASS satellites with a Proton M/Briz M vehicle; and in December, China failed in the launch of a CBERS-3 satellite with a Long March (Chang Zheng) 4B vehicle.

Russia resumed launches of Proton rockets in September 2013 and had achieved 5 consecutive successful launches in December of 2013, resulting in a slight increase in the launch success rate from the end of 2012. The next launches of the Sea Launch and Chinese Long March 4B vehicles are scheduled for 2014.

(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 IV Heavy, provided by United Launch Aliance (ULA: a joint venture of Boeing and Lockheed Martin)
- Europe: Ariane 5ECA, provided by Arianespace (prime contractors: Airbus, Safran)
- Russia: Proton M/Briz M
- Japan: H-II B
- China: Long March (Chang Zheng) 3B/G2
- India: GSLV Mk2
- Sea Launch (multinational venture): Zenit 3SL

The maximum payload to GTO of the Ariane 5ECA has increased by approximately 1 ton since the previous study. It appears that this represents an increase in the guaranteed payload value following a review of sources of error based on actual launch results. On the other hand, in the case of Russia's Proton M, it seems that the structural efficiency of this vehicle was improved by reviewing its material (composite material) and structure (lattice structure), and as a result, an actual increase in launch capacity was achieved. 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	Manufacturer /provider	Payload to GTO	Payload to LEO	Velocity increment for GSO insertion ΔV
US	Delta IV Heavy	ULA	9.7t	23.0t	1500m/s
Europe	ArianeV ECA	Arianespace	10.5t	20.0t	1500m/s
Russia	Proton M	Khrunichev	6.6t	22.3t	1500m/s
Japan	H-II B	Mitsubishi Heavy Industries	6.0t	16.5t	1500m/s*1
China	Long March 3B-G2	China Great Wall Industry Corp. (CGWIC)	5.5t	11.5t	1800m/s
India	GSLV Mk2	ISRO	2.2t	5.0t	1800m/s
Multinational	Zenit 3SL	Sea Launch	6.2t	13.9t※2	1500m/s

Source: Prepared by the Secretariat based on various materials.

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

*[2]: Theoretical value (actual data are not available).

Based on these 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 (1500m/s: 1, 1800m/s: 0.75).

Table 2-2b Evaluation of maximum capacity of launch vehicles

Item	US	Europe	Russia	Japan	China	India	Canada
GTO x Velocity increment for GSO	9.7	10.5	6.6	6.0	4.125	1.65	—
Evaluation	**9**	**10**	**6**	**6**	**4**	**2**	**0**

(Maximum possible score: 10)

Although the following are still future plans, accompanying the tendency toward large-scale geostationary satellites (mass of more than 6 tons at launch), Russia, Europe, and China are conducting reviews of the launch capacities of their launch vehicles.

Russia is developing the Angara as its next-generation main launch vehicle and is planning payload to GTO capacities of 7.5 tons for the Angara A5 and 12.5 tons for the A7.

Europe also plans to increase its launch capacity to 11.5 tons to GTO in the Ariane 5-ME and aims at improved operability in dual launches. In the Ariane 6, which is under development as Europe's next-generation launch vehicle, Europe is targeting 7 tons to GTO by converting from dual launch to single launch in order to further improve operability.

China is aiming at a maximum payload capacity of 14 tons to GTO in its Long March 5E, and if completed, this will be the largest in the world.

Small-scale launch vehicles currently perform almost no practical satellite missions for communications satellites or similar payloads. The evaluation indexes for these vehicles are the payload (satellite) mass that can be inserted into low earth orbit (LEO), sun-synchronous orbit (SSO), and polar orbit. In the present evaluation, the data for satellites of this type are simply shown in the following Table 2-2c, but the satellites are not included in the evaluation.

The main payloads that are launched by these small launch vehicles are 500kg class, as exemplified by Japan's ASNARO. However, with technical progress in 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.

Table 2-2c Performance data for small-scale launch vehicles

Country	Launch vehicle	Manufacturer /provider	Payload to SSO	Payload to LEO	Remarks
US	**Tarus XL**	**Orbital Sciences**	**1050kg**	**1600kg**	**SSO400km**
Europe	**Vega**	**Arianespace**	**1500kg**	**2300kg**	**Polar700km**
Russia	**Dnepr**	**Yuzhnoye**	**2000kg**	**3700kg**	**SSO400km**
Japan	**Epsilon**	**IHI Aerospace**	**550kg**	**1400kg**	**SSO500km**
China	**Long March 2C**	**China Great Wall Industry Corp. (CGWIC)**	**1200kg**	**3900kg**	**SSO400km**

Source: Prepared by the Secretariat based on various materials.

(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, as for a vibration environment, the types of vibration that must be considered are sine vibration and random vibration. The sine vibration environment includes environments in which the basic environmental conditions are set, and environments in which the conditions are not specified, as in the Falcon 9 launch vehicle manufactured by Space Exploration Technologies Corp. (SpaceX; headquartered in Hawthorne, California). In the latter case, it seems that the environmental conditions are not specified because large-scale satellites are involved; in cases of this type, a model for vibration analysis is supplied to the customer, and the vibration environment conditions for individual satellites are determined by analysis of vibration between the coupling and the launch vehicle structure. As the sine vibration environment conditions are distributed from 0.4G (G: acceleration of gravity = $9.8m/s^2$) to 0.9G, even in each frequency band, a comparison of the launch vehicles of the respective countries revealed no large differences. On the other hand, random vibration requirements are specified for the Proton and Zenit vehicles, but based on the sine vibration environment, again, there are no large differences in the random vibration environment in a similar way.

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 10kHz.

Table 2-3a Acoustic environment data (reference)

Country	US	Europe	Russia	Japan	China	India
Launch vehicle	Atlas V	Ariane 5	Proton M	H-II A	Long March 3B	GSLV
Acoustic OA value (db)	134	139.5	141.4	137.5	141.5	Unknown

Source: Prepared by the Secretariat based on various materials.

The shock environment in the PLF is 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. The maximum score was 10, and this was reduced by 1 point for each 500G increase. 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	DELTA IV	Ariane 5	Proton M	H-II A	Long March 3B	GSLV
Max. shock (G)	2000	2000	2000	4000	4000	Unknown
Evaluation	**10**	**10**	**10**	**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

Item	US	Europe	Russia	Japan	China	India
Vehicle	Delta IV	Ariane 5	Proton	H-II A/B	Long March 3	GSLV
1st stage main engine	RS-68	Vulcain2	RD-259	LE-7A	YF-21B	S138
Propellant	LOX/LH_2	LOX/LH_2	LOX/RP-1	LOX/LH_2	N_2O_4/UDMH	Solid
Thrust (kN)	3341	1390	10550	1098	2962	4801
Specific impulse (s)	409	434	316	440	260	266
Upper stage engine	RL10B-2	HM7B	Breeze-M	LE-5B	YF-75	KVD-1
Propellant	LOX/ LH_2	LOX/LH_2	N_2O_4/UDMH	LOX/LH_2	LOX/LH_2	LOX/LH_2
Thrust (kN)	110	64.8	19.62	137	78	75
Specific impulse (s)	462.4	445.5	325.5	448	437	460
Booster	GEM60	MPS	No booster	SRB-A	YF-20B	Vikas
Propellant	Solid	Solid		Solid	N2O4/UDMH	N2O4/UH25
Thrust (kN)	1615	5060		2260	732	760
Specific impulse (s)		275.4		283.6	259	261

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/LH_2) 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 main engine thrust: Larger values of thrust are advantageous, as gravity drag and atmospheric drag are lower. Scores were assigned as follows: Thrust of 5000kN or more: 5 points, 2500-4999kN: 4 points, and 2499kN or less: 3 points.

○ 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.

○ Booster: Boosters were evaluated only based on thrust. Points were assigned as follows: Thrust of 4000kN or more: 3 points, 2000-4000kN: 2 points, and 1999kN or less: 1 point.

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

Table 2-4b Evaluation of performance of propulsion systems

Evaluation item	Max.	US	Europe	Russia	Japan	China	India	Canada
1st stage main engine: Fuel	5	5	5	4	5	3	3	-
Upper stage engine: Fuel	5	5	5	4	5	5	5	-
1st stage main engine: Thrust	5	4	3	5	3	4	4	-
Upper stage engine: Specific impulse	5	5	4	3	4	4	5	-
Booster	3	1	3	0	2	1	1	-
Total	23	20	20	16	19	17	18	-
Evaluation		**9**	**9**	**7**	**8**	**7**	**8**	**0**

(Maximum possible score: 10)

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

- US: The J2X engine may be mentioned. This system was originally conceived as a 2-stage propulsion system for use as a Space Launch System (SLS), which is a heavy-class launch vehicle. (At present, a dual use upper-stage (DUUS) is being studied as a baseline; DUUS is to be used as a common engine with EELV.) The J2X is a gas generator cycle engine using LOX/LH_2 as the propellant. As it generates thrust of 1307kN and has a specific impulse of 448s, it is a higher performance engine than the LE-7 engine (specific impulse: 440s), which uses a staged combustion cycle with approximately the same high pressure thrust as the J2X.
- Europe: The VINCI engine, which is to be used in the upper stage of the Ariane 5ME and Ariane 6, is under development. This is an expander cycle engine (high performance closed cycle engine) which uses a LOX/LH_2 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 (low performance open 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: A 100t thrust class LOX/kerosene-fueled engine is under development for the Long March 5.
- 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 1920kN and specific impulse of 337s. As its combustion pressure is 263kgf/cm^2, this is an extremely high pressure engine, with a combustion pressure more than 2 times higher than that of Japan's LE-7A (123kgf/cm^2).
- Japan: Japan has announced a development project for the LE-9 engine, aiming at high reliability and low cost in the country's new mainstay launch vehicle. The LE-9 engine utilizes the large-scale expander bleed cycle technology of the LE-X engine (propellant; LOX/LH_2, thrust: 1618kN, specific impulse: 421s), which is currently in the technology verification stage. The new engine will be optimized for the system of the new mainstay 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 operability of the launch complexes of the respective countries, the time required for mission integration and the annual numbers of vehicles launched from the same launch complex were investigated. The results are shown in Table 2-5a.

Table 2-5a Launch complex operability data

Evaluation item	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	3-5	6	5-8	3	4	2

Source: Prepared by Secretariat based on various materials.

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. Russian and Europe had the largest numbers, followed by the US and China, and then Japan and India in that order. The results of an evaluation of launch complex operability based on these data are shown in Table 2-5b.

Table 2-5b Evaluation of launch complex operability

Country	US	Europe	Russia	Japan	China	India	Canada
Evaluation	8	10	10	6	7	4	0

(Maximum possible score: 10)

Next, multiple launches of satellites by the launch vehicles of the respective countries were investigated. These data are shown in Table 2-5c.

Table 2-5c Data on multiple satellite launches

Evaluation item	US	Europe	Russia	Japan	China	India
Simultaneous launch of multiple geostationary satellites, Technical capability	Yes ○ (Small-scale)	Yes ○ (Large-scale)	Yes ○ (Medium-scale)	No × Technical capability ○	No × Technical capability ○	No × Technical capability ○
Simultaneous launch of geostationary and LEO satellites	×	×	×	○	×	×
Launch of multiple LEO satellites	○	○	○	○	○	○

Source: Prepared by Secretariat based on various materials.

The only launch vehicle with an actual record of launching two large-scale 5 ton class geostationary satellites is Europe's Ariane 5. If the evaluation is expanded to include medium-scale geostationary satellites, Russia's Proton launch vehicle successfully launched two satellites for the first time in 2011. Japan achieved a simultaneous launch of a Geostationary Meteorological Satellite, GMS-5 (approx. 750kg) and a large-scale LEO satellite, SFU (approx. 4 tons) with the H-II launch vehicle in 1995, and also achieved a simultaneous launch of a data relay and tracking satellite, DRTS (approx. 3 tons) and a medium-scale LEO satellite, USERS (approx. 1 ton) with the H-IIA vehicle in 2002. However, from the global viewpoint, these are extremely rare combinations. This is due to the rareity of large-scale LEO satellites that perform missions at substantially the same orbit inclinations as the GTO of geostationary satellites. Japan's H-IIB launch vehicle and the America's EELV have the theoretical capability to launch two satellites simultaneously, but to date neither launch vehicle has been used for this purpose.

China independently developed an adapter for use in multiple satellite launches and has launched various combinations of satellites. Using the Long March 3B/G, China simultaneously launched two Beidou navigation satellites into medium earth orbit (MEO).

The US EELV has been used to launch a large number of singe large-scale satellites by carefully adjusting the number of boosters to match the mass of the satellite. Although there have been virtually no opportunities for multiple satellite launches, this vehicle has been used for simultaneous launch of two satellites with the same mission.

All the countries included in the present study have records of multiple LEO satellite launches.

Table 2-5d shows the results of an evaluation based on these data.

Table 2-5d Evaluation of multiple satellite launches

Country	US	Europe	Russia	Japan	China	India	Canada
Evaluation	**3**	**5**	**4**	**4**	**3**	**2**	**0**

(Maximum possible score: 5)

Table 2-5e shows the results of an evaluation of operability, considering both the operability of launch complexes and multiple satellite launches.

Table 2-5e Evaluation of launch operability

Evaluation item	US	Europe	Russia	Japan	China	India	Canada
Launch complex operability	8	10	10	6	7	4	0
Multiple satellite launches	3	5	4	4	3	2	0
Total	11	15	14	10	10	6	0
Evaluation	**7**	**10**	**9**	**7**	**7**	**4**	**0**

(Maximum possible score: 15 ⇒ Converted to maximum possible evaluation 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 with Russia's Soyuz-TMA 4 times/year and with China's Shenzhou approximately 1 time/year, respectively.

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, points were assigned on the basis of its past performance. In the US, the Natoinal Aeronautics and Space Administration (NASA) is now developing a capsule-type Multi-Purpose Crew Vehicle (MPCV) for exploration of Mars, and the private section is developing a Commercial Orbital Transportation System (COTS). The potential of the Falcon 9 launch vehicle, which was successfully developed by SpaceX, is not limited to transportation of materials to the ISS, but also extends 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. 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, as described in this chapter, a relative evaluation of the levels of the 7 main countries/regions in the space transportation systems sector was performed. In the 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.

Table 2-7 Total evaluation of space transportation systems sector

Evaluation item	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 (converted score)		**27**	**25**	**25**	**18**	**22**	**11**	**0**

(Maximum possible score: 60 points ⇒ Converted to comprehensive evaluation score assuming the maximum possible score for this sector is 30 points.)

3. Space Applications Sector

In the Space applications sector, the world's advanced space development countries were compared from the viewpoints of technical capabilities in the construction of practical systems such as satellite communication/broadcasting, earth observation, and navigational positioning. Capabilities related to operation of those systems, competitiveness for demand from other countries, etc. were also considered.

Table 3-0 shows the statistics for the number of satellites of each country by decade. These numbers themselves are not an object of this evaluation. However, looking at the period when the countries began launching satellites and the transition in the number of satellites of each country by 10-year period, it is possible to estimate, to a certain extent, the characteristics of each country's efforts in space development/use, including changes in the economic strength of the respective countries, technological improvements, etc. The total number of satellites in Table 3-1 is 6,441; however, if the number of satellites of other countries (36 countries) and international organizations/companies (5 entities) which are not shown in the table are also included, the cumulative number of satellites worldwide as of the end of December 2013 is 6,754.

Table 3-0 Number of satellite launches of countries by decade (reference)
(end of December 2013)

Decade	US	Europe	Russia	Japan	China	India	Canada
1957-1960	35	-	9	-	-	-	-
1961-1970	629	21	483	1	1	-	3
1971-1980	247	41	1053	19	7	3	6
1981-1990	234	47	1123	31	23	9	5
1991-2000	535	112	442	32	30	14	7
2001-2010	297	130	215	68	88	24	13
2011-2013	158	71	76	18	61	14	6
Total	2135	422	3401	169	210	64	40

Note: "Europe" includes satellites owned by the European Space Agency (ESA), its 17 member countries (Germany, France, etc.), and international organizations and companies such as EUMETSAT, EUTELSAT, etc.

Source: Prepared by Secretariat based on various materials.

The following compares manufacturing technology, equipment development, system implementation, operation, etc. in four important areas of the Space applications sector, namely, satellite bus technology, satellite communication/broadcasting, earth observation, and navigational positioning.

(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, communication system, etc.

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.

① Standard bus technology for geostationary satellites

In the satellite broadcasting field, satellite buses have been progressively upscaled in order to maximize use of the slot (stationary position) of the satellite in geostationary orbit, as slots are limited and thus are a valuable resource. In recent years, synchronous-orbiting communications satellites (SYNCOM) of the 5-ton to 6-ton class have become increasingly common. Therefore, standard buses for SYNCOM were compared as a representative type of standard bus. In addition to the performance, number of orders received was also compared.

In the past, American satellite manufacturers held a dominant position. More recently, however, European makers have responded to restrictions on exports under US ITAR (International Traffic in Arms Regulations ITAR), etc., by developing independent technologies, and as a result, have established their superiority.

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. The Alphasat I-XL satellite was launched as Inmarsat IV-A F4. Alphasat was developed as a multipurpose platform, for example, for high power communications satellite loads, etc. in a joint effort by Inmarsat, Astrium, and Thales Alenia Space (TAS) as a public-private partnership (PPP). Amid the trend toward large scale/large capacity in the commercial communication/broadcasting satellite market, this represented a new addition to the menu of European-made satellite buses.

In the United States, the LS-1300 type standard bus manufactured by Space Systems/Loral (SS/L) is a high level technology, as this bus can be equipped with large-scale antennas for mobile communications and the like.

China is beginning to increase its track record in exports of the independently-developed Dongfang Hong 4 satellite bus, and has won orders from Bolivia, Laos, etc. for communications satellites, which will be the first satellites for those countries.

Japan is also increasing its records of orders, for example, receiving an order from Turkey for Mitsubishi Electric's DS-2000 for two communications satellites, among others. Japan's geostationary standard bus has also been applied to weather satellites and navigational positioning satellites; these are included in Japan's record of orders received.

Russia has received orders for Israeli, Indonesian, and other satellites, incorporating European technologies.

India received an order for a satellite bus for Eutelsat.

Canada possesses element technologies but has not yet established a system that can be considered a satellite bus.

The names of the main large-scale satellite buses of each country, together with their main specifications and record of orders received, 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
US	Lockheed Martin (LM)	A2100A system	3-6t	18kW	15	70
	Boeing	BSS702 system	5-6t	17kW	15	52
	Space Systems/ Loral (SS/L)	LS1300 system	6-7t	25kW	15	115
	Orbital Sciences Corp. (OSC)	Geostar-1/-2	2-4t	5kW	15	40
Europe	Airbus (former EADS Astrium)	Eurostar-3000	5-6t	18kW	15	46
	Thales Alenia Space (TAS)	Spacebus-4000	5-6t	15kW	15	28
Russia	ISS Reshetnev	Ekspress-2000	3-4t	N/A	15	4
Japan	Mitsubishi Electric	DS-2000	3-5t	14kW	15	15
China	ChinaeAcademy of Science and Technology (CAST)	Dongfang Hong 4	5t	18kW	15	19
India	Indian Space Research Organization (ISRO)	I-3000, 4000	2-3t	N/A	10	9

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

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 3.2a.

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

	US	Europe	Russia	Japan	China	India	Canada
Evaluation	10	9	6	7	7	4	0

(Maximum possible score: 10)

② 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 are used with circular orbit-type earth observation satellites, navigational positioning satellites, etc. In Japan, the Japan

Aerospace Exploration Agency (JAXA) has a history of developing various types of engineering test satellites and scientific satellites, and has a lineup corresponding to those in the US and Europe. The Nippon Electric Co. (NEC) NEXTAR bus has been used with the ASNARO and ISAS scientific satellites and has become NEC's standard bus, and a larger-scale bus than the NEXTAR will be used with the GCOM series, which is to be launched in the future. Mitsubishi Electric's USERS, GOSAT, ADEOS, and other buses have become standard buses for satellites of various scales.

It is also necessary to evaluate each country's technical capability to produce special buses and unique buses corresponding to the special feature of mission requirements. In the United States, typical examples include the Hubble space telescope satellite, which carries a large-scale telescope, and the JWST (currently under development), which will carry a cryogenically-cooled, ultra-large-scale telescope, among others. Japan has developed dedicated buses for special mission purposes in scientific satellite such as the Hinode (SOLAR-B), which is a continuous solar observation satellite, and exploratory satellites including the Kaguya (SELENE), Hayabusa (Muses-C), and others. Japan also has a growing record of manufacture and launches of ultra-small-scale satellites (CubeSats) for educational and other purposes, centering on universities.

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

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

(Maximum possible score: 10)

③ 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.

Parts on satellites remain highly dependent on the United States, and the superiority of that country remains unchallenged; 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.

In element technologies and components, all countries are attempting to secure strategic superiority. As examples, Japan has numerous items with high international competitiveness, such as solar cell panels, lithium-ion batteries, etc., and Canada has outstanding technical capabilities in 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

Evaluation item	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
Total evaluation		10	10	3	6	3	2	2

(Maximum possible score: 10)

④ 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	Astrium	Boeing	LMCSS	Orbital	SS/L	CGWIC	Mitsubishi Electric
Representative buses	Spacebus -3000, -4000	Eurostar -2000, -3000	BSS -602, -702	A2100	Star-2	LS-1300	DFH-4	DS-2000
Evaluation	4	5	5	5	4	4	3	5

(Maximum possible score: 5)

Based on these data, there is considered to be no difference 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)

⑤ Information disclosure

With satellites used in service businesses, for example, communications satellites, importance is attached to objective indices of quality and reliability such as orbital life, reliability, and the like. In contrast, emerging countries tend to attach greater importance to low cost in educational satellites and "starter" satellites. China is actively marketing satellites to emerging countries and as a result, now has a growing record of orders. However, these satellites tend to have a higher frequency of trouble than ordinary commercial satellites. In the case of China, this appears to be affected by the difficulty of making an objective evaluation of the technology in advance due to limited information disclosure.

For this reason, rather than evaluating satellite bus technology based simply on the number of orders received, it is also necessary to consider the extent to which the manufacturing country encourages information disclosure. The results of an evaluation of disclosure of information related to satellite bus technology are shown n Table 3-1g.

Table 3-1g Evaluation of information disclosure

	Max.	US	Europe	Russia	Japan	China	India	Canada
Evaluation	2	2	2	1	2	1	1	2

(Maximum possible score: 2)

⑥ **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 3-1h.

Table 3-1h Total evaluation of satellite bus technology

Evaluation item	Max.	US	Europe	Russia	Japan	China	India	Canada
Standard bus technology	10	10	9	6	7	7	4	0
Lineup	10	10	10	8	8	6	6	1
Parts, etc.	10	10	10	3	6	3	2	2
Reliability	5	5	5	2	5	3	2	0
Information disclosure	2	2	2	1	2	1	1	2
Total	37	37	36	20	28	20	15	5
Evaluation		**10**	**10**	**5**	**8**	**5**	**4**	**1**

(Maximum possible score: 37 ⇒ Converted to maximum evaluation score: 10)

(2) Satellite communication/broadcasting

① Development of satellite communication/broadcasting technology

Among the various uses of satellites, the greatest progress in commercialization has been in the field of satellite communications and broadcasting. Technological development has also progressed, including expanded use of defense communication technologies. The main directions in technical development include expansion of the lineup of geostationary satellites (larger scale, smaller scale), increases in the number of transporters, use of new frequency bands, large-scale antenna technology for mobile communications, broadband related technologies to eliminate the "digital divide," multibeaming and increased transmission capacity by active phased array antenna (APAA) technology, inter-satellite communication including optical communications, etc. As a result of efforts to extend satellite life to approximately 15 years, progress has been made in research on reconfigurable technology for flexibly changing mission service in response to changes in demand.

Because the United States consistently led the world in the development of advanced technologies for satellite communications until the 1980s, there was feeling that the US is technically mature. For this reason, NASA discontinued technical development of new communication/broadcasting satellites in 1993, after which its activities were limited to operation of tracking and data relay satellites (TDRS), which are necessary in manned space activities and earth observation. TDRS are satellites which are procured based on established designs. On the other hand, satellite manufacturers such as Boeing and others, which develop large-scale technologies for private-sector communications companies and satellite communications system in new bands for the US Department of Defense (DOD), are grappling with leading-edge issues such as continuing upscaling of satellites, improvement of reliability/satellite life, etc., and possess top-level technical capabilities thanks to the system of technology transfer of advanced technologies, which were originally developed as defense communication technologies, to private-sector communication/broadcasting satellites.

In Japan, JAXA has developed a number of satellites for satellite communications technology development. These include the communications technology test satellite Kakehashi (COMETS), the data relay and tracking satellite Kodama (DRTS), the inter-satellite optical communications experiment satellite Kirari (OICETS), the engineering test satellite Kiku 8 (ETS-VIII), and the ultra-high speed internet relay satellite Kizuna (WINDS), among others. As a result of its R&D on new satellite communications technologies, Japan has made many important technical achievements, and its range of communications technologies now exceeds that of Europe. However, because Japan has discontinued plans for satellites for development of communications technologies, there is an undeniable feeling that the country will be relegated to a subordinate role in more advanced Ka band communications technology, reconfiguration technology, and other cutting-edge technologies in the future.

Europe is engaged in technical development in the satellite communications field in the ARTES program, in which the European Space Agency (ESA) is developing advanced communications technologies; examples include the Alphabus and a bus for small-scale geostationary communication/broadcasting satellite, etc. Europe's satellite manufacturing companies are competing with the US by forming multinationals and creating mass-production systems with the collaboration of the respective countries.

As a recent trend, England's O3b (Other Three Billion) Networks announced in September 2008 its goal of creating a new "constellation" satellite data system comprising 16 O3b satellites in low orbits approximately 8,000km above the Equator and providing low-cost broadband service to developing countries and regions. The company succeeded in launching its first four satellites in 2013. O3b Networks receives funding from the American company Google. As its name suggests, the mission of the O3b satellites is to service providing high speed, low cost internet linkage to the "other 3 billion" people in Asia, Africa, Latin America, and the Middle East who are currently without internet access.

China developed a world-class communication/broadcasting satellite in the Dongfang Hong 4 bus, and also developed the tracking and data relay satellite Tianlian 1. In 2012, China launched the 3rd satellite in the series, Tianlian 1C, which is equipped for rendezvous docking of manned spacecraft.

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

Evaluation item	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	0	1	0	1	0	0	0
Evaluation		9	9	1	5	1	0	0

(Maximum possible score: 10)

② Missions of satellite communication/broadcasting

Among the missions of satellite communication/broadcasting, television broadcasting is the largest user. The proportion of international communications and the like has decreased accompanying construction of land and undersea optical cables. In general, the contribution of satellite communications is small in the advanced countries, where land infrastructure has been completed. On the other hand, in the emerging countries and developing countries, which are geographically large and still lack land infrastructure, satellite communications serves as part of the communications infrastructure, and the range of applications is expanding. In particular, remote learning and remote medicine have attracted attention.

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.

Whether a country possesses technologies suitable for mobile communications and broadband or not is also a meaningful indicator when evaluating its technological capabilities.

Based on the above, Table 3-2b shows the results of an evaluation of satellite communication/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

Evaluation item	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	0	0	2	0	2	1
Remote medicine	2	1	0	0	1	0	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	5	4	7	5	7	7
Evaluation		4	2	2	3	2	3	3

(Maximum possible points: 12 ⇒ Converted to maximum evaluation score: 5 points)

③ 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. Here, a comparison will be made based on the sales data of fixed satellite communication/ broadcasting companies in 2012.

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), which is headquartered in Luxembourg; 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. China's China Satcom is ranked 6th, Russia's Russian Satellite Communications Company is ranked 13th, and India's Antrix is ranked 16th. In addition to China Satcom, which operates both military communications satellites and commercial communications satellites, Chinese companies also include Asiasat, which operates Asiasat, and Asia Broadcast Satellite (ABS) in Hong Kong. The revenues of these three companies in total slight exceed those of the Japanese company SKY Perfect-JSAT. In Japan, BSat also ranked in the top 25 until 2009 because satellite broadcasting 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.

Satellites in the communication/broadcasting field are not limited to a single country; 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 calculation.

The concrete data are shown in Table 3-2c.

Table 3-2c Number of satellite communication/broadcasting companies and sales revenues in 2012 (top 25)

Item	US	Europe	Russia	Japan	China	India	Canada
Number of companies	2	5	3	1	3	1	1
Sales (million USD)	2699	4,540	370	659	672	160	846

Source: Prepared by Secretariat based on various materials.

Note 1: The No. 1 company, Intelsat (US$2,360 million) is headquartered in Luxembourge; however, because it has historically been considered a US company, it was listed as an American company in this calculation.
Note 2; The 9 other companies in the top 25 include 4 in East Asia, 2 in the Middle East, 2 in Central and South America, and 1 in Africa.

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

	US	Europe	Russia	Japan	China	India	Canada
Evaluation	4	5	2	3	3	1	3

(Maximum possible score: 5)

④ **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

Evaluation item	Max.	US	Europe	Russia	Japan	China	India	Canada
Technical development	10	9	9	1	5	1	0	0
Missions	5	5 4	2	2	3	2	3	3
Companies	5	4	5	2	3	3	1	3
Total	20	17	16	5	11	6	4	6
Evaluation		**9**	**8**	**3**	**6**	**3**	**2**	**3**

(Maximum possible score: 20 ⇒ Converted to maximum evaluation score: 10)

(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, support for agriculture and forestry, etc. The advanced countries are also engaged in activities for social implementation of space-based earth observation systems such as monitoring of global warming/environmental pollution, mitigation of disaster damage, use in primary industries, and the like.

For reference, the following shows the earth observation satellites currently in operation, together with satellites scheduled for launch in recent years (shown in *italics*) by country.

(a) US

Earth observation:	EOS-Terra/Aqua/Aura, OSTM/JASON, TRMM, GPM, QuickSCAT, ACRIMS, SORCE, EO-1, Landsat, OCO, CloudSat, CALIPSO, Aquarius, *SMAP*, ICE-Sat, GRACE, KH, GeoEye, IKONOS, Worldview, NOSS
Meteorological observation:	GOES, NOAA, DMSP, Suomi-NPP, JPSS

(b) Europe

Earth observation:	TerraSAR-X, TanDEM-X, RapidEye, SPOT, Sentinel, GOCE, SMOS, Cryosat, SWARM, Aelous, EarthCARE, SAR-Lupe, Helios, COSMO-SkyMed, Pleiades
Meteorological observation:	MeteoSat/MSG, MetOp

(c) Russia

Earth observation:	Resurs, Kanopus, Kosmos
Meteorological observation:	Elektro, Meteor

(d) Japan

Earth observation:	TRMM, AMSR-E, GOSAT, GCOM-W, GCOM-C, GPM, ALOS, EarthCARE
Meteorological observation:	MTSAT

(e) China

Earth observation:	CBERS, Zi Yuan (ZY), Huan Jing (HJ), Tian Hui (TH)、Gao Fen (GF), Hai Yang (HY), Yao Gan (YG)
Meteorological observation:	Feng Yun (Fy) (geostationary and polar orbits)

(f) India

Earth observation:	SARAL, RISAT, Megha-Tropiques, RECOURCESAT, CARTOSAT, OCEANSAT
Meteorological observation:	INSAT,KALPANA

(f) Canada (examples)

Earth observation:	Radarsat, RCM, PCW

Emerging countries in space development are also active in earth observation. Although not directly related to the present study, the following presents a brief introduction of the activities of those countries.

Korea began from KITSAT, which was based on the Great Britain SSTL satellite bus. More recntly, Korea developed the Arirang (KOMPSAT) series of circular orbit satellites based on overseas technologies introduced from the United States and Europe. In recent years, Korea has mainly placed orders for satellites with Europe's Airbus (formerly Astrium) and TAS. Where geostationary satellites are concerned, Korea acquired a multipurpose satellite COMS also using a European satellite bus. In small-scale satellites, the Satrec Initiative is continuing independent development efforts from KITSAT, and exports to other countries have been seen recently. Although Korea has a small-scale system development capability, it must unavoidably depend on purchases from other countries for medium- to large-scale practical satellites. It also seems that Korea lacks the parts production capacacity which serves as the foundation for research on core parts (optical systems, sensors, etc.) which are necessary in the development of sensor equipment. Korea can be seen as promoting 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 have begun to acquire observation data with their own satellites, which are to be launched with the cooperation of foreign countries.

① 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 range of types of earth observation activities is indicative of the range of earth observation capabilities (technical capabilities).

In the previous study, 9 items were evaluated, these being meteorological observation, land observation, relief mapping, marine observation, radar observation, resource exploration, atmospheric observation, ELINT (Electronic Intelligence), and COMINT (Communication Intelligence). However, in the present study, these were reorganized into 7 evaluation items from the viewpoints of observation domain and mission specificity; the 7 items considered here are meteorological observation, atmospheric observation, marine observation, land observation, relief mapping, resource exploration, and radio exploration (ELINT/COMINT). The evaluation results are shown in Table 3-3a.

Table 3-3a Evaluation of earth observation missions

Mission	Max.	US	Europe	Russia	Japan	China	India	Canada
Meteorological observation	3	3	3	2	2	3	2	0
Atmospheric observation	2	2	2	1	2	1	1	0
Marine observation	2	2	2	0	2	1	1	1
Land observation	2	2	2	1	2	2	1	1
Relief mapping	2	2	2	0	2	1	2	0
Resource exploration	2	2	1	1	2	1	1	1
Radio exploration (ELINT/COMINT)	1	1	0	1	0	0	0	0
Total	14	14	13	6	12	9	8	3
Evaluation		10	9	4	9	6	6	2

(Maximum possible points: 14 ⇒ Converted to maximum possible evaluation score: 10)

② Earth observation sensor technology

In evaluating the types and performance of earth observation sensors, 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 capabilites) has a strong correlation with the levels of the related sciences in each country, consideration of those factors is also necessary in an evaluation.

○ Outline of sensors

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 reconnaissance satellites, and wavelength resolution is generally a priority in the mission of environmental observation satellites. Since a tradeoff relationship exists among these various capacities, it is not possible to satisfy all of these performance requirements with a single satellite. In recent years, however, 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 installing many types of observation devices on a single large-scale platform 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 polar-orbiting weather satellites (e.g., JPSS (US), MetOP (Europe), FY (China)) 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.

○ Visible light resolution

The satellite with the world's highest spatial resolution is the US reconnaissance satellite Keyhole (KH), which is thought to have resolution on the order of 10-15cm (actual capability is unknown). Among satellites whose capabilities have been disclosed, the US commercial imaging satellite GeoEye-2 has resolution of 34cm. However, due to the tradeoff relationship between earth surface resolution and wide-area photography, 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. Therefore, it is necessary to optimize the balance between resolution and wide-area characteristics depending on the purpose of photography (buildings on land/roads/rivers/vehicles/human beings, etc.)

○ Synthetic aperture radar

In principle, synthetic aperture radar (SAR) complements the observational features of optical sensors. That is, when photography is possible, detailed information can be collected by visible light observation, but this is impossible at night and during cloudy weather. In contrast, although the resolution of radar is inferior to that of visible light, radar enables observation under all weather conditions, including at night. SAR for use on satellites has been realized by the C-band (Canada), C/X-band (US), X-band (Europe), L-band (Japan), and S-band (China). Transmission characteristics (e.g., rainfall attenuation, etc.) differ depending on the respective frequencies, and there are differences, namely, earth surface resolution is determined physically. Because Japan's unique L-band is sensitive to water vapor, it can be used to obtain qualitative information on the condition of water vapor in the atmosphere, the amount of water on the ground surface, and the like. Thus, this band is suited to forest identification and flood damage-related observation, and is widely used as a technology for obtaining types of information not limited to shape. By obtaining the interference between ALOS synthetic aperture radar and the observational database accumulated from JERS-1, it is also possible to evaluate movements of the Earth's crust with centimeter-order precision. For example, in Japan, the evaluations of the amount of movement of the Earth's crust over a wide region before and after the Great East Japan Earthquake of 2011 and the Hanshin-Awaji Earthquake of 1995 are still fresh in memory.

○ Multiband sensors

Optical 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 is now being succeeded by VIIRS (Visible Infrared Image Radiometer Suite) of Suomi-NPP as a succeesor sensor. Extremely high precision is required in these radiometers. Although Japan's GLI (Global Imager) aboard the ADEOS-2 has approximately the same performance, operation was stopped due to a satellite anomaly. GLI is scheduled to be succeeded by SGLI, which will be mounted on the GCOM-C; the first launch of the No. 1 satellite in that series planned for 2016. 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. Due to the high precision required in radiometers, development is difficult except in the advanced countries. Europe is developing the Sentinel-2 and China is developing the FY-3 for the same purpose.

○ Hyperspectral sensors

Hyperspectral sensors 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 include Sciamachy on Europe's Envisat and the AIRS, OCO, etc. of the United States. The Japanese hyperspectral sensor GOSAT (Greenhouse Gases Observing Satellite) is used in observation of CO_2. As spectroscopy methods, Europe and the US mainly use the diffraction grating method, while Japan and Canada have adopted the Fourier spectrometer.

○ Laser radar

The United States is the leader in laser radar (LADAR). The fact that the life of the high output laser transmitters used in earth observation was shorter than the design life was a common technical problem worldwide. However, the US solved this problem in the development of the CALIPSO and now possesses the world's only long-life laser transmitter technology for earth observation. Europe is currently developing an ultraviolet laser transmitter for insallation in the Aelous and EarthCARE, and is seeking to overtake the US. Japan realized a compact laser altimeter for use in lunar exploration, and is currently engaged in research on a high output, long-life laser transmitter technology.

○ Meteorological sensors

Various countries have installed domestically-developed meteorological sensors in weather satellites in geostationary orbit. Amid this trend, Japan depended on imports of US sensors, and as a result, has very little experience in the development of meteorological sensors. With the exceptions of Japan and Canada, other countries are discontinuing development in which multispectural 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.

○ Sensors for early warning satellites

Only the US (DSP) and Russia have realized practical application of sensors for early warning satellites, but the technical details of those devices are not known. France completed the launch of a test satellite (Spirale), and China is also hastening to develop a technology of this type. While Japan possesses potential technical capabilities, it is necessary to accelerate research and development, particularly of infrared area sensors.

○ Status of sensor development by country

The United States and Europe are engaged in development work which includes virtually all types of sensors. However, the US has an overwhelming advantage in both performance and technical capabilities.

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 has made intense efforts to catch up in recent years, for example, through cooperation with Europe (Dragon Program and introduction of test equipment), activities of overseas researchers in Europe and the US, etc. However, it will be necessary monitor future results in order to ascertain the extent of China's capacity to do independent R&D. At present, it appears that China, like India, is in the R&D stage where observation systems are concerned.

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 transform infrared spectrometer (FTS) technology, 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 it is engaged in a comprehensive range of research so as avoid gaps in technology. In areas where it has begun satellite development as a mission, Japan has secured its international position by demonstrating either the world's only technology or the world's high performance. Examples of "world's only" technologies include the L-band phased array SAR system (PALSAR) of ALOS, Ku/Ka band precipitation radar of GPM, W-band Doppler radar of EarthCARE, and Fourier spectrometer for CO_2 measurement of GOSAT. Moreover, AMSR of GCOM-W can be cited as a world-class technology microwave scanner sensor. 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.

The results of an evaluation of the various sensor technologies is shown in Table 3-3b.

Table 3-3b Evaluation of earth observation sensor technologies

Evaluation item	Max.	US	Europe	Russia	Japan	China	India	Canada
Visible light resolution	2	2	2	1	2	1	1	0
Synthetic aperature radar	2	2	2	0	2	1	0	2
Multiband sensors	2	2	1	1	2	1	0	0
Hyperspectral sensors	2	2	1	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
Early warning satellites sensors	2	2	1	2	0	1	0	0
Total	14	14	10	6	8	6	3	3
Evaluation		10	7	4	6	4	2	2

(Maximum possible points: 14 ⇒ Converted to maximum possible evaluation score: 10)

③ **Public use**

How the data collected by the many satellites that various countries have launched can contribute to public use, for example, in disasters, health, climate change, and the like, is a subject of much discussion, particularly in the US and Europe, which are new completing general technical development.

The 10-year plan (2006-2015) called "Global Earth Observation System of Systems (GEOSS)" is a global initiative in in the field of earth observation. The aim of GEOSS is social application of monitoring and observation data in 9 fields related to social benefit, such as disasters, health, weather, agriculture, etc., not simply by observation from space, but by integrated observation with in-situ monitoring systems, including land, marine, and atmospheric observation and others.

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, the EU is now implementing a system for environmental monitoring and security covering Europe and Africa under the name Copernicus: The European Earth Observation Programme (formerly known as GMES: Global Monitoring for Environment and Security). This program is not limited to implementation and operation of the satellite system, but also includes actual use of satellite data for public purposes. Copernicus is also Europe's contribution to GEOSS.

Japan's contribution to GEOSS will center on 3 of the 9 fields of social use, "Global warming/changes in global carbon cycle," "Climate change/changes in water cycle," and "Disasters". Japan also implemented a satellite system applicable to the field "Others". In parallel with this, Japan studied a data integration and analysis system (DIAS) for integration and use of the obtained satellite observation data and ground observation data. However, at present, this is not firmly established as soical infrastructure or a system for social implementation. Thus, for Japan, creation of infrastructure and social implementation corresponding to that in Europe and the US will be necessary as urgent issues for the future.

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 on public issues, for example, disaster mitigation and observation of climate change, and Canada is devoting considerable effort to observation of domestic water resources by utilizing the performance of its radar satellites.

With completion of the 10-year GEOSS program now approaching, discussion of the next period of the GEOSS program, as well as discussion of Future Earth, which aims to integrate the world's three scientific communities and similar initiatives has now begun.

Regarding meteorological observation, the World Meteorological Organization (WMO) has constructed a global observation system which covers the entire planet by comprehensive use of the satellites of all countries and enables mutual exchanges of data. Concretely, the satellite observation network World Weather Watch (WWW) is made up of groups of geostationary satellites, comprising Himawari (Japan), GOES (US), Meteosat (Europer), Electro (Russia), INSAT/Kalpana (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). Japan is making an international contribution by its geostationary satellites, but depends on foreign parts for infrared sensors for cloud observation on those satellites. Japan has no circular orbit satellites for weather observation and depends on the data of circular orbit satellites of other countries.

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

Evaluation item	Max.	US	Europe	Russia	Japan	China	India	Canada
Integrated systems	3	3	3	0	1	0	0	0
Disaster	3	3	3	1	3	2	2	2
Health	3	2	2	0	0	0	0	0
Energy	3	2	2	0	0	0	0	1
Weather	3	3	3	3	2	3	2	0
Water	3	3	2	1	3	0	1	2
Climate change	3	3	3	0	3	2	2	2
Ecosystems	3	2	3	0	0	1	0	2
Agriculture	3	2	3	1	1	1	1	2
Biodiversity	3	2	3	0	0	1	0	1
Total	30	25	27	6	13	10	8	12
Evaluation		8	9	2	4	3	3	4

(Maximum possible points: 30 ⇒ Converted to maximum possible evaluation score: 10)

④ Commercial use (satellite manufacture/sale, satellite imaging)

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 (formerly EADS Astrium), TAS, and others have multiple results of satellite sales to emerging countries in Africa and Asia. Canada also developed the German RapidEye by using RadarSat technology. Korea' Satrec Initiative has manufactured small-scale earth observation satellites for Malaysia, the United Arab Emirates, and Spain.

China is engaged in joint development of satellites with Brazil and also manufactured a small-scale earth observation satellite for Venezuela. 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 and components 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).

The business of satellite imaging includes sale of reception rights and sale of images. Companies in the US and Europe have recorded sales in the form of sale of reception rights to users who can operate receiving stations.

Images as such are sold to users who lack receiving stations. The US, Europe (France, Germany), Russia, 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. In Europe, Astrium GEO-Information Services sells commercial images acquired by SPOT, Pleiades, TerraSAR, and other satellites. In Russia, the national enterprise Earth Observation Center (NTs OMZ) and RDC ScanEx perform services using images from satellites of other countries. IKI Data Distribution Service sells images acquired by Russian satellites. In India, Antrix sells images from the ISRO's earth observation satellites to customers around the world. In Canada, RadarSat images are sold by MacDonald Dettwiler and Associates Ltd. (MDA).

In Japan, the private company PASCO and the general incorporated foundation Remote Sensing Technology Center of Japan (RESTEC) have sold commercial satellite images from ALOS, as well as from the satellites of other countries.

In the case of China, it is thought that images are distributed among public research institutions and national enterprises. However, there still appear to be no satellite image sales companies in China.

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)

Evaluation item	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	0	2	1
Evaluation		4	5	2	1	1	2	2

(Maximum possible score: 5)

⑤ International cooperation

International cooperation in earth observation satellites was evaluated based on two items, participation in the International Disaster Charter and regional cooperation.

○ 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. Because Japan discontinued operation of the ALOS in May 2011, it can no longer acquire the most recent images; in the past, however, it contributed by providing many images. At present, Japan is contributing by providing archive data and performing image processing for satellites of other countries. Japan expects to regain its image acquisition capability with the launch of the radar satellite ALOS-2.

The participating organizations of each country are as follows.

- US, 2 organizations: NOAA, USGS (also, Digital Globe, GeoEye)
- Europe, 5 organizations: ESA, CNES (France; also, Astrium, NSPO (Taiwan)), DLR (Germany), DMC (Great Britain; in addition, Argeria, Nigeria, Turkey, SSTL), and EUMETSAT.

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

○ Regional cooperation

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. Europe has also implemented the DRAGON Program as cooperation with China, and is now continuing joint earth observation research with China.

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 frame 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 Asia Pacific Space Cooperation Organization (APSCO, 8 participating countries), and APSCO itself is also participating in APRSAF.

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

Table 3-3e Evaluation of international contribution

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

(Maximum possible points: 8 ⇒ Converted to maximum possible evaluation score: 5)

⑥ Summary of earth observation

Table 3-3f shows the results of an evaluation of the levels of earth observation of the respective countries based on the individual evaluation results presented above.

Table 3-3f Total evaluation of earth observation

Evaluation item	Max.	US	Europe	Russia	Japan	China	India	Canada
Mission diversity	10	10	9	4	9	6	6	2
Sensor types/performance	10	10	7	4	6	4	2	2
Public use	10	8	9	2	4	3	3	4
Satellite sales/image sales	5	4	5	2	1	1	2	2
International contribution	5	2	5	1	4	2	1	1
Total	40	34	35	13	24	16	14	11
Evaluation		**9**	**9**	**3**	**6**	**4**	**4**	**3**

(Maximum possible points: 40 ⇒ Converted to maximum possible evaluation score: 10)

(4) 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 determind user's position/time in the service area at all times.

A satellite positioning system which coveres 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.

① 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 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 SIS-URE described in the published standards of systems at the United Nations' 8th International Committee on GNSS (IGC).

In the case of GPS and GLONASS, these are Root Mean Square (RMS) values for all satellites including older generations. Therefore, when making comparisons between those systems and newer systems, it is necessary to note that the figures for other systems are for individual satellites and the evaluation only includes new satellites. In spite of this difference, GPS displays the highest performance. This system has continued to perform stably over the long term, and its satellites and ground systems have been modernized.

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（RMS）
US	GPS	0.8m (RMS of all operational satellites)*1
Russia	GLONASS	1.8m (RMS of all operational satellites)*2
China	BeiDou	1.0-2.0m (by satellite; 14 satellite system)
Europe	Galileo	1.26m (IOV No. 1 satellite)
Japan	QZSS	0.4m (Michibiki)
India	IRNSS	—

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

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

○ 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 x 10^{-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	System	Onboard atomic clock manufacturing capability	Atomic clock performance (stability)
US	GPS	Yes (Cs, Rb)	$1\text{-}8\times10^{-14}$@ 1 day (Rb clock on Block-IIR, IIR)
Europe	Galileo	Yes (passive hydrogen maser, Rb)	8×10^{-15}@ 1 day (passive hydrogen maser on GIOVE-B) 5×10^{-14}@ 1 day (Rb on GIOVE-A)
Russia	GLONASS	Yes (Cs)	$2\text{-}8\times10^{-14}$@100000s *1
Japan	QZSS	No *2 (Rb)	—
China	BeiDou	Yes (Rb)	$2.5\text{-}9.4\times10^{-14}$@1day
India	IRNSS	— *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: Whether the onboard atomic clock of the IRNSS was actually manufactured in India or not is unknown, as this information has not been disclosed.

○ 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 precise orbit/clock estimation technologies at the present time. A list of IGS analysis centers is shown in Table 3-4c. 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. It is estimated that Russia does not have precise orbit/clock estimation technology on the IGS analysis center level. India carried out its first launch only very recently, as its SIS-URE has not yet been evaluated; therefore, it is estimated as lacking precise orbit/clock estimation technology of the IGS level.

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 10 for SIS-URE, scores were assigned as follows: <1m: 10, 1-1.5m: 8, >1.5m: 6. India was given a score of zero as no data were available. Japan was given a score of -2 as it does not have atomic clock manufacturing technology, and Russia was given -1 point as it does not have an IGS analytical center organization. The results of this evaluation are shown in Table 3-4d.

Table 3-4d　Comparison of system construction technologies

Evaluation item	Max.	US	Europe	Russia	Japan	China	India	Canada
SIS-URE	10	10	8	6	10	6	—	—
Atomic clock	—	—	—	—	-2	—	—	—
Precise orbit estimation	—	—	—	-1	—	—	—	—
Evaluation	10	10	8	5	8	6	0	0

(Maximum possible score: 10)

② Satellite constellation technology

"Constellation" means a technology for coordinated operation of multiple satellites. Constellation is a critical technology, because, unlike the applications of other satellites, positioning is a service which is realized 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 2013, 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 2013, 7 IIRm satellites and 4 IIF satellites had been launched and were in operation. Additon of a L1C signal to the L1 band is planned beginning from the Block-III satellites, which are scheduled for launch starting in 2015. 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 2013, Russia had 28 satellites in orbit and operating, including 1 test satellite and 3 backup satellites. 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 Oceana (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 January 2014, service is provided by a total of 14 satellites, comprising 5 geostationary earth orbit (GEO) satellites, 5 inclined geosychronous satellite orbit (IGSO) satellites with 8-shaped ground tracks like those of quasi-zenith satellites, and 4 medium earth orbit (MEO) satellites. The services provided are public signals for civil use, secuirity 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.

In the Galileo system being constructed by Europe, a total of 30 satellites will be placed in orbit, 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. A total of 4 in-orbit validation (IOV) satellites have been launched (2 each in 2011 and 2012), and system verification is progressing. Six satellites are scheduled for launch during 2014, and the start of first-stage service is planned by 2015.

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. System study is in progress in the Space Strategy Office, Cabinet Office of Japan.

India is constructing the regional satellite positioning system IRNSS, which will provide open service and public regulated servie 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.

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, and the average value of PDOP (Position DOP) 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

Item	US	Europe	Russia	Japan	China	India
No. of satellites necessary (GNSS)	27	30	24	-	35	-
" (RNSS)	-	-	-	4 to 7	14*	7
No. of operational satellites	31	4	28	1	14	1
Condition of implementation or operation	Operation	Implement-ation	Operation	Implement-ation	Operation	Implement-ation
Record of stable service**	20 years	—	2 years	—	1 year	—
PDOP***	1.96	—	4.39	—	3.48	—

* Expansion of China's BeiDou system in steps from RNSS to GNSS is planned; as of the end of 2013, China was providing regional service with a constellation of 14 satellites.

** 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 BeiDou for its service region, i.e., latitude 55°N to latitude 55°S, longitude 55°E to 180°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.

Table 3-4f Evaluation of satellite constellation performance

	US	Europe	Russia	Japan	China	India	Canada
Evaluation	10	2	6	1	4	1	0

(Maximum possible score: 10)

③GNSS 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 ICAO (International Civil Aviation Organization). The WAAS (Wide Area Augmentation System) in the United States, EGNOS (European GNSS Navigation Overlay Service) in Europe, and MSAS (MTSAT Satellite Augmentation System) in Japan are currently operational, and India's GAGAN (GPS And Geo-Augmented Navigation system) and Russia's SDCM (System of Differential Correction and Monitoring) are in the implementation stage.

At present, it is thought that a technical comparison of the SBAS of the respective countries is possible based on the operational phase of aircraft that operate using SBAS. The US system, WAAS and the European EGNOS provide APV service (APV: Approach and landing with vertical guidance, i.e., approach and landing guidance with precision integrity assurance in the vertical direction). In the area around Japan, the geographical environment for ionosphere compensation is more difficult than those in the US and Europe, which are close to the magnetic equator. Therefore, Japan's MSAS provides enroute and NPA service (NPA: Non-Precision Approach), and is of a lower level than the systems in the US and Europe, as vertical precision and integrity are not assured. In the case of India's GAGAN and Russia's SDCM, confirmation has not been completed, and their status is "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. 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 augmenation 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.

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	To 10cm		World	GPS GLONASS	TDRS Internet
	Trimble	Centerpoint RTX	PPP-AR	To 2cm		World	GPS GLONASS QZSS	GEO satellite Internet
Europe	CNES	PPP-Wizard	PPP-AR	To 2cm	5cm	World	GPS GLONASS	Internet
	Terrastar	TerrastarD	PPP	5cm	10cm	World	GPS GLONASS	GEO satellite Internet
Japan	SPAC	CMAS	PPP-RTK	3cm	6cm	Japan	GPS	QZSS
	JAXA	MADOCA	PPP	10cm	10cm	East Asia Oceana	GPS GLONASS QZSS	QZSS

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	—
Carrier wave phase Augmentation	4	4	4	—	1	—	—	—
Total	8	8	8	1	3	0	1	0
Evaluation	4	4	4	1	2	0	1	0

(Maximum possible points: 8 ⇒Converted to maximum possible evaluation score: 4)

④ **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

Evaluation item	Max.	US	Europe	Russia	Japan	China	India	Canada
SIS-URE	10	10	8	5	8	6	0	0
Constellation	10	10	2	6	1	4	1	0
GNSS augmentation technology	4	4	4	1	2	0	1	0
Total	24	24	14	12	11	10	2	0
Evaluation	**10**	**10**	**6**	**5**	**5**	**4**	**1**	**0**

(Maximum possible points: 24 ⇒Converted to maximum possible evaluation score: 10)

(5) Summary of Space applications sector

Table 3-5 shows the results of a total evaluation of the Space applications sector, synthesizing the results of study of the four fields presented in this chapter.

Table 3-5　Total evaluation of Space applications field

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

(Maximum possible points: 40 ⇒Converted to maximum possible evaluation score: 30)

4. Space Science Sector

Space science missions have been carried out since the early stages of space development. These include lunar and planetary exploration, astronomical observation, and observation of the geospace environment, among others. During 2013, India launched a Mars probe and China launched a lunar lander. If India's Mars probe is successfully inserted into a Mars orbit in 2014, it will be Asia's first Martian orbiter. China successfully achieved Asia's first landing on the Moon's surface on December 14, 2013. The United States also launched lunar and Mars explorers, and international cooperation between the United States and India can be seen in Martian exploration. In the US, NASA has proposed a unique plan which involves capturing a small asteroid and towing it to near the Moon; this project was included in the President's budget for FY 2014. In the future, there is also a possibility that the United States, Russia, Europe, Japan, China, India, and other countries will carry out large-scale space exploration projects in a framework of international cooperation, like the International Space Station (ISS), with the participating countries contributing technology and funding. The US has taken the initiative in promoting the development of a 4-person manned spacecraft and a heavy lift launch vehicle for future Martian exploration. Although Canada has no experience in launching independent space probes, it is contributing by supplying the robot arm for NASA's Mars explorer, etc.

(1) Lunar/planetary exploration

① Lunar exploration

Reaching the moon, which is the nearest celestial body to the Earth, was a goal from the early days of space development. In the 1960s, the United States and the former Soviet Union conducted advanced exploratory activities which were not limited to orbiting the Moon, but also included landing on the Moon's surface and collecting samples, etc. In the Apollo program, the United States succeeded in landing astronauts on the Moon, carrying out scientific explorations on the Moon's surface, and returning the astronauts safely to Earth a total of six times between 1969 and 1972.

In 2007, Japan's lunar orbiter Kaguya (Selene) was launched, followed by China's Chang'e 1, and in 2008, India also launched a lunar orbiter, Chandrayaan 1. Thus, expanding cooperation and competition can be seen among various countries including the US and Europe as well. The United States announced the Constellation human spaceflight program during the Bush Presidency, but this was later cancelled by the Obama Administration, and the US is now aiming at human exploration of Mars and asteroids. Europe is also putting effort into Martian exploration in cooperation with Russia. Amid these circumstances, China's Chang'e 3 made a successful soft landing on the lunar surface in December 2013 and began scientific missions, including separation of a lunar rover called Yutu (Jade Rabbit), and mutual photography of the landing vehicle and rover, etc. However, a "mechanical abnormality" occurred at the start of shutdown of Yutu for the second lunar night in January 2014. After reactivation from the sleep mode in February, the rover was able to perform communication and observation, but travel was not possible.

Table 4-1a shows the basic data on the lunar explorers of the countries concerned.

Table 4-1a Basic data on lunar explorers

Item	US	Europe	Russia	Japan	China	India
Number of lunar explorers	28	1	30	2	3	1

Source: Prepared by the Secretariat based on various materials.

② Planetary exploration

Planetary exploration encompasses a large number of objects; in addition to the inner planets (Mercury, Venus, and Mars) and the outer planets (Jupiter, Saturn, Uranus, and Neptune), nonplanetary targets include exploration of asteroids and comets, exploration outside the Solar System, etc. The United States has launched probes to all of these object celestial bodies. Since the US has launched many large-scale scientific satellites and probes, including the Voyagers (extrasolar exploration), Galileo (exploration of Jupiter), Cassini (exploration of Saturn), Ulysses (solar exploration), and the Mars Surveyor (exploration of Mars), among others, the country now holds an unrivalled position, particularly in exploration of the outer planets, which requires a special power source.

In addition to probes for exploration of the inner planets, Europe has also obtained a large amount of scientific knowledge by supplying some of the observation equipment for NASA probes. For example, Europe developed the Huygens Saturn probe carried by NASA's Cassini as an outer-planet explorer in cooperation with the US. Europe also launched an independent Halley's comet probe, Giotto.

Russia has experience in launching probes to Venus, Mars, and Halley's comet. Future exploration plans include the Moon, Mars, and Venus.

In Japan, the space science sector is developing small-scale probes based on an independent concept and has launched the comet probe Suisei (PLANET-A), the Mars probe Nozomi (PLANET-B), and the Venus probe Akatsuki (PLANET-C). Although Japan's record is not comparable to those of the US and Russia, its achievements now rank with those of Europe. The Japanese asteroid probe Hayabusa (MUSES-C) was a bold plan, in spite of the small scale of the satellite itself, and attracted worldwide attention by successfully collecting rock samples from the surface of an asteroid and returning the samples to Earth. Although Japan's Mars probe Akatsuki, which was launched in 2010, failed to achieve insertion into a Mars circular orbit in 2011, the country is now preparing for the challenge of a new Mars mission several years from now. Among future launch plans, Japan is currently developing a Mercury Magnetosphere Orbiter (MMO) for the Mercury Exploration Project BepiColumbo, which is to be carried out jointly with Europe.

Although China and India did not have experience in launching planetary probes as of 2011, those countries developed Mars probes which were launched in 2011 and 2013, respectively. China's probe, Yinghou 1, was launched on the Russian Fobos-Grunt sample return spacecraft, but the satellite failed to achieve insertion into a Mars transfer orbit and fell into the sea with the launch vehicle.

India's Mars probe Mangalyaan was launched in November 2013 and was successfully inserted into a Mars transfer orbit at the end of that month. It is scheduled to approach Mars after a flight of about 10 months and be inserted into an extended elliptical orbit around that planet during September 2014.

Table 4-1b shows the data arranged on the basis of the above.

Table 4-1b Data on planetary exploration

Item	US	Europe	Russia	Japan	China	India
Number of planetary probes (including comets and asteroids)	42	4	32	4	1	1
Number of object planets (not including comets and asteroids)	5 or more	2	2	2	1	1

Source: Prepared by the Secretariat based on various materials.

③ Record of return to Earth

In exploring the Moon and planets, the main method is to approach the object, collect data by satellite, and transmit the collected data back to Earth by radio. Although it is difficult to land directly on the Moon or a planet, collect materials, and then return to Earth, it goes without saying that the scientific value of the mission also increases. Therefore, the record of returning satellites, etc. to Earth in the space science activities of the respective countries was also considered as an object of evaluation.

Japan's asteroid probe Hayabusa not only flew to the point furthest from the Sun, but also successfully returned to Earth 7 years after its launch. The countries which have records of landing on the Moon or planets, collecting specimens, and returning those specimens to Earth are limited to the United States and Russia. The concrete data are shown in the following Table 4-1c.

Table 4-1c Data on results of return to Earth

Item	US	Europe	Russia	Japan	China	India
Record of return to Earth	2 or more	None	2 or more	1	None	None

Source: Prepared by the Secretariat based on various materials.

④ Evaluation from scientific viewpoint

As an evaluation from the scientific viewpoint, this study compared the number of papers presented in Lunar and Planetary Science Conferences, in which many scientists in this field participate. The data are shown in the following Table 4-1d.

Table 4-1d Data on number of papers presented in LPSC

Item	US	Europe	Russia	Japan	China	India	Canada
Number of papers presented in LPSC	402	91	3	34	2	1	9

Source: Prepared by the Secretariat based on various materials.

⑤ **Results of evaluation of lunar/planetary exploration**

Table 4-1e shows the results of an evaluation of lunar/planetary exploration based on the data presented above.

Table 4-1e Evaluation of lunar/planetary exploration

Evaluation item	Max.	US	Europe	Russia	Japan	China	India	Canada
Number of lunar probes	3	3	1	3	1	2	1	0
Number of planetary probes	4	4	1	3	1	1	1	0
Number of object planets	2	2	1	1	1	1	1	0
Record of return to earth	1	1	0	1	1	0	0	0
Number of papers published in LPSC	10	10	6	1	4	1	1	2
Evaluation		**20**	**9**	**9**	**8**	**5**	**4**	**2**

(Maximum possible score: 20)

(2) Astronomical observation

① Number of astronomical observation satellites

In space science, astronomical observation means missions in which various types of telescopes are mounted onboard scientific satellites in space orbits in place of telescopes installed in land-based astronomical observatories. By type of observation sensors, these can be divided into visible light telescopes, infrared telescopes, ultraviolet telescopes, X-ray telescopes, gamma ray telescopes, radio telescopes, microwave telescopes, helioscopes (solar telescopes), distance measuring instruments, and others.

With the exception of VLBI (Very Long Baseline Interferometry), the United States has experience in the development and operation of all types.

Europe has independently developed and operated large-scale X-ray telescopes and gamma ray satellites, etc., and has also actively participated in US-led large-scale missions such as the Hubble (astronomical observation), Compton Gamma Ray Observatory (GRO), and others.

Japan has realized mission with special features in the X-ray, infrared, and radio regions, although these missions were small in scale. X-ray astronomical observation is a special strength of Japan, and the country has an independent position in the cooperative international system for X-ray observation. In particular, the ASTRO-H, which is now in the development stage, makes full use of Japan's advanced observation technologies and will have the highest sensitivity in the past over a wide wavelength region. In addition to large-scale participation from the US, this instrument is being developed with broad cooperation by scientists of many countries. Recently, Japan's solar observation satellite Hinode achieved the highest spatial resolution in history in solar observation, and in the infrared region, Japan's infrared astronomical observation satellite Akari has realized an all-sky survey with the world's highest sensitivity and resolution, showing that Japan is continuing to expand its fields of expertise. Japan is also participating in overseas missions, for example, by large-scale participation in the international large-area gamma ray satellite Fermi, etc.

Russia launched the Spektr-R in 2011, creating a system for radio astronomy observation by its own satellites.

Canada is also considered to perform astronomical observation from space, based on its partial participation in NASA projects and European projects.

China and India still do not have experience in launching astronomical observation satellites; however, China is currently developing the hard X-ray satellite telescope HXST, and India is developing an astronomical observation satellite called Astrosat.

As an item for evaluating astronomical observation from the engineering viewpoint, the cumulative number of astronomical observation satellites to the end of 2013 was used. Since November 2011, the US, Europe, Japan, and Canada have each launched one satellite. The concrete data are shown in Table 4-2a.

Table 4-2a Cumulative number of astronomical observation satellites

Item	US	Europe	Russia	Japan	China	India	Canada
Number of astronomical observation satellites	68	17	11	13	0	0	2

Source: Prepared by the Secretariat based on various materials.

②Scientific viewpoint

As an item for evaluation of astronomical observation from the scientific viewpoint, the 5-year average Impact Factor (IF) of the scientific journals of the respective countries in 2012 was used. Although the evaluation includes papers related to ground observation, inclusion of ground observation was considered meaningful from the viewpoint of technical capabilities.

The source of information on IF is the database of Thomson Reuters (formerly ISI). The following journals in the category of Astronomy & Astrophysics were adopted as objects of evaluation. No comparable data were available for Canada.

Europe: Astronomy and Astrophysics (AA)
Russia: Astronomy Reports
US: The Astrophysical Journal (ApJ)
China: Chinese Journal of Astronomy and Astrophysics
Japan: Publications of the Astronomical Society of Japan (PASJ)
India: Journal of Astrophysics & Astronomy

The actual IF values are given in Table 4-2b.

Table 4-2b IF data of scientific journals

Item	US	Europe	Russia	Japan	China	India
IF of scientific journal	5.945	4.422	0.707	3.062	0.849	0.336

Source: Prepared by the Secretariat based on various materials.

③ Results of evaluation of astronomical observation

First, an evaluation is made based on the number of astronomical observation satellites. Based on the data in Table 4-2a, and assuming a maximum possible score of 10, evaluation scores were calculated by dividing the cumulative number of satellites by 3 and rounding up the result. In the case of the US, because that country has a total of 68 satellites, the calculated result would exceed the maximum possible score; therefore, the US was assigned the maximum possible score of 10.

Next, in the academic evaluation, based on the data in Table 4-2b and assuming a maximum possible score is 10, the IF of the respective countries was rounded off, and the result (upper limit: 10) was used as the evaluation score.

The sum of the two above-mentioned scores was used as the total evaluation of the astronomical observation field. The results are shown in Table 4-2c.

Table 4-2c Evaluation of astronomical observation

Evaluation item	US	Europe	Russia	Japan	China	India	Canada
Number of astronomical observation satellites	10	6	4	5	0	0	1
IF of scientific journals	6	4	1	3	1	0	0
Evaluation	**16**	**10**	**5**	**8**	**1**	**0**	**1**

(Maximum possible score: 20)

(3) Observation of geospace environment

The space environment surrounding the Earth includes the magnetosphere, ionosphere, radiation belt (Van Allen belt), etc. Since the early days of space development, countries have carried out space science missions to investigate these space environments surrounding the Earth. In particular, the existence of the Van Allen belt was discovered as a result of satellite launches for the first time for mankind. Although the existence of the magnetosphere and ionosphere was known predated space development, their detailed natures were clarified by launching rockets and satellites.

① Number of space environment observation satellites

From the engineering viewpoint, the number of space environment observation satellites was used as an evaluation index for comparison of the countries in the field of geospace environment observation.

One of Japan's strengths is exploration of the magnetosphere. GEOTAIL (Geophysical Tail Resources Satellite), which was developed jointly with the United States, has produced many results and is still in operation. Europe launched a three-satellite group called SWARM in 2013 and plans to carry out research on the Earth's magnetosphere.

Since 2012, Europe, China, and Canada have increased their number of satellites by a total of 5. Regarding China, among satellites which were formerly considered to be engineering test satellites, it is now clear that the main mission of the 20 satellites in the Shijian (Practice) series is space environment observation; therefore, the number of Chinese space environment satellites was increased from the previous 5 to 25. The data on the number of satellites in this field are shown in Table 4-3a.

Table 4-3a Number of space environment observation satellites

Item	US	Europe	Russia	Japan	China	India	Canada
Number of space environment observation satellites	101	56	78	9	25	3	5

Source: Prepared by the Secretariat based on various materials.

② Scientific viewpoint

For evaluation from the scientific viewpoint, this study compared the number of Committee on Space Research (COSPAR) conferences held, as scientists in many fields participate in these events, and the share of papers presented at COSPAR conferences.

COSPAR conferences are mainly held in Europe and the US, and the other 5 countries have held only 1 or 2 such meetings. Russia is scheduled to hold its 2^{nd} COSPAR meeting during 2014.

The ratio of papers presented at COSPAR conferences by country was investigated by sampling the 39th COSPAR Scientific Assembly held in 2012. It was found that the US accounted for approximately 60% of papers presented, followed by Europe (approx. 20%) and Japan (approx. 10%). The shares of Russia, China, India, and Canada, which were also objects of the present evaluation, were estimated at about 2% each.
The actual results of the above are shown in Table 4-3b.

Table 4-3b Basic data on observation of geospace environment

Item	US	Europe	Russia	Japan	China	India	Canada
Number of COSPAR conferences (until 2013)	5	23	1	2	1	2	2
Share of papers presented at COSPAR (calculated assuming all papers = 10)	6	2	0.2	1	0.2	0.2	0.2

Source: Prepared by the Secretariat based on various materials.

③ Summary of evaluation of observation of geospace environment

Scores for the number of space environment observation satellites were given as follows: <10 satellites: 1, increased by 1 point for each 10 satellites; 60 or more satellites: 7 (maximum possible score).

For the number of COSPAR conferences held, assuming a maximum possible score of 3, scoring was as follows: 1 meeting: 1 point, 2 meetings: 2 points, 3 or more meetings: 3 points. The scores for the share of papers presented at COSPAR conferences were calculated by multiplying the share of papers shown in Table 4-3b by 3 and rounding off the results; the US was assigned the maximum possible score of 10 points, as its score exceeded 10.

The technical evaluation of the countries in the field of geospace environment observation was performed by adding the three above-mentioned scores. The results are shown in Table 4-3c.

Table 4-3c Evaluation of observation of geospace environment

Evaluation item	Max.	US	Europe	Russia	Japan	China	India	Canada
Number of space environment observation satellites	7	7	6	7	1	3	1	1
Number of COSPAR meetings held	3	3	3	1	2	1	2	2
Share of papers presented at COSPAR	10	10	6	1	3	1	1	1
Evaluation		**20**	**15**	**9**	**6**	**5**	**4**	**4**

(Maximum possible score: 20)

(4) Summary of space science sector

Table 4-4 shows the results of the total evaluation of the space science sector based on the individual evaluation results presented above.

Table 4-4 Total evaluation of space science sector

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

(Maximum possible score: 60 ⇒Converted to maximum possible evaluation score: 20)

5. Manned Space Activities Sector

In July 2011, the US space shuttle Atlantis made its final flight, and the space shuttle program came to an end after a period of 30 years. In August of the same year, a Soyuz rocket carrying a Russian Progress cargo transport crashed over Siberia due to an upper stage engine malfunction, resulting in postponement of the launch of a Soyuz manned spacecraft, which had been scheduled for September 22 using the same rocket. If it was not possible to resume Soyuz transport in November, it was feared that there would be no means of transporting crews from the Earth to the International Space Station (ISS), and the ISS would temporarily be in a completely unmanned condition. However, the cause of the malfunction was idendified, the launch of a Soyuz rocket carrying a manned spacecraft was set for November 14, and it was possible to turn over the mission to a new crew within a short time.

At the present time, the US does not have an independent manned space flight capability. However, because manned transportation by the SpaceX Dragon spacecraft, development of NASA's Multi-Purpose Crew Vehicle (MPCV), and others are now taking concrete shape, there is a high possibility that America will regain an independent manned space flight capability within several years.

Although China had not experienced a rocket launch failure since 1996, the launch of a Chang Zheng (Long March) 2C type rocket failed in August 2011. As a result, the launch of the space station experimental vehicle Tiangong 1, which had been scheduled around for September using a Long March 2F in the same series, was postponed until September 29.

Europe and Japan do not have independent manned space flight capabilities. However, they are contributing the operation of the ISS by developing respective independent cargo transport vehicles.

Canada is also contributing to the ISS program by supplying robot arms. India is in the stage of planning manned space flight.

Based on these circumstances, technical capabilities in the manned space activities sector were evaluated by setting evaluation criteria for five items, i.e., manned spacecraft and operations control technology, manned space stay technology, manned space activity support technology, space environment experiment technology, and manned space exploration technology.

(1) Manned spacecraft and operations control technology

As evaluation criteria for manned spacecraft, the record of space flight of systems linked to manned spacecraft (e.g., manned stay systems, cargo transport systems, etc.), etc., scores were assigned corresponding to the difficulty and level of achievement of the respective criteria. That is, the maximum score is given if the difficulty of the evaluation criterion is high and the level of achievement is also high, but the score is lower if the degree of difficulty is low, even assuming the highest level of achievement. Regarding operations control technology, because it is difficult to assign a separate quantitative level for this item, this was considered by inclusion in the various evaluation criteria and was not treated as an independent evaluation criterion.

① Number of manned spacecraft flights

The evaluation was made corresponding to the number of flights of manned spacecraft. Scores were assigned as follows: 50 or more space flights: 5 points, 10 or more flights: 4 points, 2 or more flights: 3 points, 1 flight: 2 points, no flights of manned spacecraft, but record of unmanned spacecraft flight to ISS: 1 point, no flights: 0 points. The US and Russia both already have records of more than 50 space flights and were given 5 points. China, which has 5 flights, was given 3 points. The evaluation results for the number of manned spacecraft flights are shown in Table 5-1a.

Table 5-1a　Evaluation of number of manned spacecraft flights

	Max.	US	Europe	Russia	Japan	China	India	Canada
Number of manned spacecraft flights	5	5	0	5	0	3	0	0

② Manned spacecraft technology

The technical level of the manned spacecraft flown by the countries was evaluated corresponding to the degree of difficulty. Concretely, scores were assigned as follows: Record of manned spacecraft for deep-space exploration: 5 points, record of flights of low earth orbit (LEO) manned spacecraft (reusable): 4 points, record of flights of LEO manned spacecraft (non-reusable): 3 points, no record of flights of manned spacecraft: 0 points. The US was given 5 points, as it has made manned spaceflights to the Moon and also has reusable manned spacecraft technology. Russia and China were given 3 points, as they have non-reusable manned spacecraft technologies for LEO orbits near the Earth. The evaluation results for manned spacecraft technology are shown in Table 5-1b.

Table 5-1b　Evaluation of manned spacecraft technology

	Max.	US	Europe	Russia	Japan	China	India	Canada
Manned spacecraft technology	5	5	0	3	0	3	0	0

③ **Record of cargo transport vehicle flights**

Technology for cargo transportation from the Earth's surface to manned stay facilities is a large technological step toward manned spacecraft development. This field of technology was evaluated by whether or not a country has a record of developing such technologies and flying actual transport vehicles; 2 points were given if the country had a record of these activities. Although China does not have a record of cargo transportation in the narrow sense, it was judged that China possesses this technology, as a country which has manned spacecraft technology clearly has the capability to transport cargos. Accordingly, the US, Europe, Russia, Japan, and China were each given 2 points. The results of the evaluation of the record of flights of cargo transport vehicles are shown in Table 5-1c.

Table 5-1c Evaluation of record of flights of cargo transport vehicles

	Max.	US	Europe	Russia	Japan	China	India	Canada
Record of flights of cargo transport vehicles	2	2	2	2	2	2	0	0

④ **Record of flights of cargo recovery vehicles**

As in the case of flights of cargo transport vehicles, technology for recovery of cargos from space was evaluated by whether or not a country has a record of developing this type of technology and flying actual vehicles. Countries with a record of these activities received 2 points. Both Europe and Japan have ballistic flight recovery records. Accordingly, the US, Europe, Russia, Japan, and China were each given 2 points. The results of the evaluation of the record of flights of cargo recovery vehicles are shown in Table 5-1d.

Table 5-1d Evaluation of record of flights of cargo recovery vehicles

	Max.	US	Europe	Russia	Japan	China	India	Canada
Record of flights of cargo recovery vehicles	2	2	2	2	2	2	0	0

⑤ **New development plans**

In case a country has concrete plans for the development of a new manned spacecraft, it was judged that the country had secured a considerable level of technology. The US, Russia, and China were each given 1 point (maximum score). The results of the evaluation of new development plans are shown in Table 5-1e.

Table 5-1e Evaluation of new development plans

	Max.	US	Europe	Russia	Japan	China	India	Canada
New development plan	1	1	0	1	0	1	0	0

⑥ **Summary of manned spacecraft and operations control technology**

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

Table 5-1f Evaluation of manned spacecraft and operations control technology

Evaluation item	Max.	US	Europe	Russia	Japan	China	India	Canada
Number of flights of manned spacecraft	5	5	0	5	0	3	0	0
Manned spacecraft technology	5	5	0	3	0	3	0	0
Record of cargo transport vehicle flights	2	2	2	2	2	2	0	0
Record of cargo recovery vehicle flights	2	2	2	2	2	2	0	0
New development plans	1	1	0	1	0	1	0	0
Evaluation		**15**	**4**	**13**	**4**	**11**	**0**	**0**

(Maximum possible score: 15)

(2) Manned stay in space technology

The level of achievement of technology for astronauts to "stay" in space and the number of astronauts with actual spaceflight experience, which would seem to be strongly related to the level of that technology, were used as evaluation criteria, and points were assigned corresponding to the difficulty and level of achievement of the respective technologies.

① Life and environment support technologies

The countries in this study have developed technologies such as air regeneration, water regeneration, humidity control, air circulation, etc.; therefore, whether the countries have a record of actually flying actual spacecraft using these technologies was evaluated. Countries like the United States, Russia, and China, which have records of flight with air regeneration, water regeneration, humidity control, and air circulation were given 3 points, and those like Europe and Japan, which only have flight records of humidity control and air circulation, were given 2 points. The evaluation results are shown in Table 5-2a. It may be noted that humidity control includes large capacity waste heat technology, and air circulation includes fire detection and extinguishing.

Table 5-2a Evaluation by life and environment support technologies

	Max.	US	Europe	Russia	Japan	China	India	Canada
Life/environment support technologies	3	3	2	3	2	3	0	0

② Sanitation and health management technologies

The US, Russia, and China, which possess extensive records in both sanitation technologies and health management technologies, were given 3 points. Europe and Japan, which have actual results with only one of these two technologies, were given 2 points. The evaluation results are shown in Table 5-2b. Sanitation technologies including toilets and showers; health management includes meals, health monitoring and management during, before, and after flights, and in-orbit medical care.

Table 5-2b Evaluation of sanitation and health management technologies

	Max.	US	Europe	Russia	Japan	China	India	Canada
Sanitation/health management technologies	3	3	2	3	2	3	0	0

③ Manned module technologies

As manned module technologies, whether a country has developed technologies such as pressurized structures, hatches, docking/berthing ports, meteorite and debris protection, large capacity electric power, communications, man-machine interface, system monitoring and control, etc. and has a record of flights of actual vehicles or not was evaluated.

Because the US, Europe, Russia, and Japan have developed these technologies and have records of flight of actual vehicles, these countries were given 3 points. Although China does not currently have orbital facilities, it has a record of flights of manned vehicles; based on this, it was judged that China possesses manned module technologies, and 3 points were given. The results of the evaluation of manned module technologies are shown in Table 5-2c.

Table 5-2c Evaluation of manned module technologies

	Max.	US	Europe	Russia	Japan	China	India	Canada
Manned module technologies	3	3	3	3	3	3	0	0

④ Cumulative days in space of astronauts

Time (cumulative days) in space of astronauts was one evaluation item. The records for this item are US: 16,188 days, Russia: 22,714 days, Europe: 1,734 days, Japan: 742 days, China: 59 days, Canada: 506 days, and India: 8 days. Based on these data, the US and Russia, which each have more than 10,000 days in space, were given 5 points; Europe, which has more than 1,000 days, was given 4 points; Japan and Canada, with more than 100 days, were given 3 points; China, with more than 10 days, was given 2 points; and India, with more than 1 day, was given 1 point. The evaluation results are shown in Table 5-2d.

Table 5-2d Evaluation of cumulative days in space of astronauts

	Max.	US	Europe	Russia	Japan	China	India	Canada
Cumulative days in space of astronauts	5	5	4	5	3	2	1	3

⑤ Summary of manned stay in space technology

Table 5-2e shows the results of the evaluation of manned stay in space technology based on the individual evaluations presented above.

Table 5-2e Evaluation of manned stay in space technology

Evaluation item	Max.	US	Europe	Russia	Japan	China	India	Canada
Life/environment support technologies	3	3	2	3	2	3	0	0
Sanitation/health management technologies	3	3	2	3	2	3	0	0
Manned module technologies	3	3	3	3	3	3	0	0
Cumulative days in space of astronauts	5	5	4	5	3	2	1	3
Evaluation		**14**	**11**	**14**	**10**	**11**	**1**	**3**

(Maximum possible score: 14)

(3) Manned space activity support technology

The levels of space suit and support robot technology were evaluated as technologies supporting the activities of astronauts in space.

① Space suit technology

The US, Russia, and China, which have developed the technologies of space suit development and already have records of flight with actual space suits were given 3 points. The results of the evaluation of space suit technology are shown in Table 5-3a.

Table 5-3a Evaluation of space suit technology

	Max.	US	Europe	Russia	Japan	China	India	Canada
Space suit technology	3	3	0	3	0	3	0	0

② Support robot technology

Countries with records of support robot flight are limited to Japan and Canada in the ISS. Development of Europe's European Robot Arm (ERA) has been completed, but this device still has no flight record. The US Robonaut has been launched but has virtually no actual results at the present time. Japan and Canada, which have records of support robot development and flight, were given 3 points, and the US and Europe, which have records limited to support robot development, were given 2 points. The results of the evaluation of support robot technology are shown in Table 5-3b.

Table 5-3b Evaluation of support robot technology

	Max.	US	Europe	Russia	Japan	China	India	Canada
Support robot technology	3	2	2	0	3	0	0	3

③ Summary of manned space activity support technology

Table 5-3c shows the results of the evaluation of manned space activity support technology based on the individual evaluations presented above.

Table 5-3c Evaluation of manned space activity support technology

Evaluation item	Max.	US	Europe	Russia	Japan	China	India	Canada
Space suit technology	3	3	0	3	0	3	0	0
Support robot technology	3	2	2	0	3	0	0	3
Evaluation		**5**	**2**	**3**	**3**	**3**	**0**	**3**

(Maximum possible score: 6)

(4) Space environment utilization experimental technology

The level of manned space environment utilization experimental technology was evaluated based on the record number of experiments in space medicine, life sciences, and microgravity science.

① Space medicine experimental technology

The US, Europe, and Russia, which have records of more than 30 experiments, such as experiments using the country's own crew, radiation measurement, etc., were given 2 points. Japan, which has conducted more than 5 such experiments, was given 1 point. The results of the evaluation of space medicine experimental technology are shown in Table 5-4a.

Table 5-4a Evaluation of space medicine experimental technology

	Max.	US	Europe	Russia	Japan	China	India	Canada
Space medicine experimental technology	2	2	2	2	1	0	0	0

② Life science experimental technology

The US, Europe, Russian, and Japan, which have records of more than 30 in-orbit experiments related to the life sciences, were given 2 points. Canada, which has a record of more than 5 such experiments, was given 1 point, and China and India, which have each conducted fewer than 5 experiments, were given 0 points. The results of the evaluation of life science experimental technology are shown in Table 5-4b.

Table 5-4b Evaluation of life science experimental technology

	Max.	US	Europe	Russia	Japan	China	India	Canada
Life science experimental technology	2	2	2	2	2	0	0	1

③ Microgravity scientific experimental technology

The US, Russia, and Japan, which have records of more than 30 experiments involving microgravity environments in fields such as material engineering, fluid physics, combustion materials, etc., were given 2 points. Europe and Canada, which have 5 or more such experiments, were given 1 point, and China and India, with fewer than 5 experiments each, were given 0 points. The results of the evaluation of microgravity scientific experimental technology are shown in Table 5-4c.

Table 5-4c Evaluation of microgravity scientific experimental technology

	Max.	US	Europe	Russia	Japan	China	India	Canada
Microgravity scientific experimental technology	2	2	1	2	2	0	0	1

④ **Summary of space environment utilization experimental technology**

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

Table 5-4d Evaluation of space environment utilization experimental technology

Evaluation item	Max.	US	Europe	Russia	Japan	China	India	Canada
Space medicine experimental technology	2	2	2	2	1	0	0	0
Life science experimental technology	2	2	2	2	2	0	0	1
Microgravity scientific experimental technology	2	2	1	2	2	0	0	1
Evaluation		**6**	**5**	**6**	**5**	**0**	**0**	**2**

(Maximum possible score: 6)

(5) Manned space exploration technology

The items evaluated in this category were surface movement technology (rover technology) and regolith-resistant space suit technology, which are necessary in manned exploration of the surface of other celestial bodies such as the Moon, Mars, etc., as well as the actual record of manned exploration activities. "Regolith" means a blanket-like layer of deposited materials consisting of impact fragments of meteors, fine powder of bedrock broken down by the action of space weathering, etc., which is distributed on the surfaces of celestial bodies such as the Moon, some planets, asteroids, etc.

① Surface movement technology

The countries were evaluated based on whether they have a record of developing technologies for movement on the surface of the Moon, Mars, etc. and space flight of actual vehicles. The US was given 4 points, as it has a record of operation of the lunar rover, which supports manned use. Russia was given 2 points, as it has a record of operation of an unmanned rover. Europe, Japan, China, India, and Canada have no records of operation of rovers, but were given 1 point each because they are engaged in demonstration of such devices on Earth and related research and development. As the condition of China's lunar rover Yutu is not clear, that rover was not considered as an object of the present evaluation. The results of the evaluation of surface movement technology are shown in Table 5-5b.

Table 5-5a Evaluation of surface movement technology

	Max.	US	Europe	Russia	Japan	China	India	Canada
Surface movement technology	4	4	1	2	1	1	1	1

② Regolith-resistant space suit technology

The US was given 3 points, as it has a record of developing space suit technology with resistance to regolith on the surface of the Moon, Mars, etc. and use of actual regolith-resistant space suits. Russia, which is engaged in research and development for operation on other celestial bodies, was given 1 point. The results of the evaluation of regolith-resistant space suit technology are shown in Table 5-5b.

Table 5-5b Evaluation of regolith-resistant space suit technology

	Max.	US	Europe	Russia	Japan	China	India	Canada
Regolith-resistant space suit technology	3	3	0	1	0	0	0	0

③ Record of manned space exploration activities

The record of manned exploration of celestial bodies other than the Earth, as such, is considered to be an important index in the sense that it demonstrates that diverse systems can be operated in an integrated manner. The US was given 5 points because it has an actual record of manned exploration of the Moon, and other countries were given 0 points, as they have no similar records. The results of the evaluation of the record of manned exploration activities are shown in Table 5-5c.

Table 5-5c Evaluation of record of manned exploration activities

	Max.	US	Europe	Russia	Japan	China	India	Canada
Record of manned exploration activities	5	5	0	0	0	0	0	0

④ Summary of manned space exploration activities

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

Table 5-5d Evaluation of manned space exploration technology

Evaluation item	Max.	US	Europe	Russia	Japan	China	India	Canada
Surface movement technology	4	4	1	2	1	1	1	1
Regolith-resistant space suit technology	3	3	0	1	0	0	0	0
Record of manned space exploration activities	5	5	0	0	0	0	0	0
Evaluation		**12**	**1**	**3**	**1**	**1**	**1**	**1**

(Maximum possible score: 12)

(6) Summary of manned space activity sector

Table 5-6 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

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

(Maximum possible score: 53 ⇒Converted to maximum possible evaluation score: 20)

Appendix: Members of the Study Group for International Comparison of Space Technology

(in Japanese phonetic order)

Chair	Shigeru Aoe	Former Deputy Chair, Space Activities Commission, Ministry of Education, Culture, Sports, Science and Technology
Member	Taku Izumiyama	Technology Group Leader, Space Development Dept., Aero-Engine & Space Operations, IHI Corporation
Member	Hideaki Uchikawa	Associate Senior Engineer, Next Generation Space Vehicle Research Office, Space Vehicle Technology Center; Human Spaceflight Mission Directorate, Japan Aerospace Exploration Agency
Member	Koichi Okita	Director, Space Transportation System Research and Development Center, Space Transportation System Research and Development Center, Japan Aerospace Exploration Agency
Member	Toshiyoshi Kimura	Associate Director for Engineering, Earth Observation Research Center, Satellite Applications Mission Directorate I, Japan Aerospace Exploration Agency
Member	Satoshi Kogure	Mission Leader, Satellite Navigation Office, Satellite Applications Mission Directorate I, Japan Aerospace Exploration Agency
Member	Tomohiko Goto	Director for Space Transportation Systems, Sales Department, Space Systems Division, Aerospace Systems, Mitsubishi Heavy Industries, Ltd.
Member	Takayuki Toma	Deputy General Manager, Space System Department, NEC Corporation
Member	Saburo Matsunaga	Professor, Department of Space Flight Systems, Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency
Member	Hisayuki Mukae	General Manager Office for Space Utilization & Strategy Planning Space Systems Division, Mitsubishi Electric Corporation
Member	Atsushi Murakami	Deputy Manager, Sales Department, IHI Aerospace Co., Ltd.
Member	Junichi Watanabe	Vice-Director General, National Astronomical Observatory of Japan, and Director, Astronomy Data Center
Secretariat	Yukihide Hayashi	Senior Fellow, Center for Research and Development Strategy, Japan Science and Technology Agency
Secretariat	Teruhisa Tsujino	Visiting Fellow, Center for Research and Development Strategy, Japan Science and Technology Agency