R&D Activities of Electric Propulsion in Japan

IEPC-2015-28／ISTS-2015-b-28

Presented at Joint Conference of 30th International Symposium on Space Technology and Science 34th International Electric Propulsion Conference and 6th Nano-satellite Symposium, Hyogo-Kobe, Japan July 4 – 10, 2015

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Abstract: Hayabusa has come back by means of microwave discharge ion engines in 2010. This is the first mission in Japan to apply electric propulsion as the main thruster for orbit transfer. Previously, electric propulsion system has been used for north-south keeping for geostationary satellites. From the end of 1990s, application to the orbit transfer of small scientific satellite has started by success of the ion engine for Deep Space 1. And now Falcon9 launched two all-electric satellites Boeing's 702SP which weigh about 2000kg each the half weight of the other same power class satellites owing to changing chemical propellant to Xenon used for ion engine, 2015/2/March. Beyond that, International Space Exploration Coordination Group (ISECG) has discussed about orbit transfer system from the low earth orbit to earth-moon Lagrange point by using electric propulsion system in the Global Exploration Roadmap (GER). Against this background, higher power electric propulsion system has been developed for in-space propulsion system which transport materials from the orbit to the orbit in the world recently. JAXA has started conducting a study on high power electric propulsion system as a candidate for in-space propulsion system with many universities and companies. We explain the status of research and development about several electric thruster , like hall thruster, MPD thruster, and approach on high power electric propulsion system in Japan.

I. Introduction

Effective space transportation systems are needed to expand the field of space activities beyond the low earth orbit. Plasma propulsions, or electric propulsions are promising technologies for the orbital transportation for future large-scale missions due to their high specific impulse, that is, high propellant consumption efficiency.

Electric propulsion is an energy conversion device that convert electric energy into kinetic energy of plasma jet through electrostatic, electromagnetic or electrothermal acceleration that propel orbital spacecrafts. It has been used for attitude control of GEO (geosynchronous orbit) satellites like ETS series and for orbit transfer of space exploration probes like Hayabusa asteroid explorer in Japan so far. Now days, electric propulsions begin to be

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applied to orbit rising for GEO satellites as well, i.e. all-electric satellites, because they give great cost reduction to launch it. A great attention has been paid to electric propulsion system especially high power, more than 5 kW class systems.

The International Space Exploration Coordination Group, ISECG, has been discussing human space exploration toward the Moon, NEAs (Near Earth Asteroids), and Mars, as a following activity after the retirement of International Space Station, ISS. They have been insisting on the necessity of high power electric propulsion systems for these missions as shown in Fig. 1.

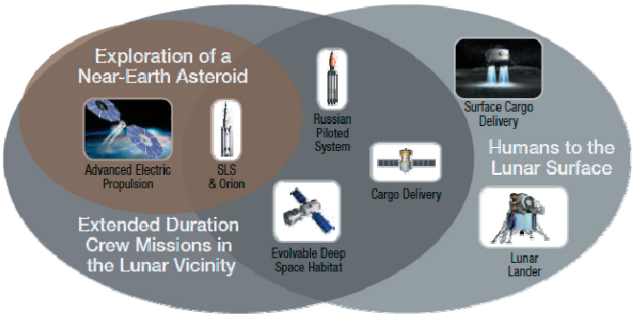


Fig. 1 Critical technologies for human space exploration

Japan Aerospace Exploration Agency, JAXA, has been contributing to the establishment and operation of ISS for many years, and now considering the contribution to the future international space exploration by Japanese own space technologies. Electric propulsion is one of the candidates because Japan ha lots of heritage in this field.

In this paper, R&D activity of electric plasma propulsions in Japan toward to these missions will be explained.

II. World Trend of Electric Propulsion Usage

A. All-electric Satellite

Boeing announced that they contracted to build up to four communications space craft, with all-electric propulsion system in 2012. Two of these satellites, 702SP was launched together 2015/2/March. Rather than them, three U.S. government satellites were contracted in 2013 and two more communications were in 2015. 702SP has 5kW class ion thruster which has been proven by many flights for not only controlling but also orbit transfer instead of chemical propulsion. Although it needs about six months for orbit transfer, it would make possible to launch two satellites at one time by significant propellant weight reduction owing to changing chemical propellant to Xenon used ion engine. It may be very attractive for satellite users seeking lower launch costs and longer satellite lifetimes. Also. other satellite bus of big manufactures, like Lockeed martin A2100 and Space Systems/Loral LS1300 are developing their all electric version with hall thruster.

In Europe, ESA has decided to develop and demonstrate all- electric satellite responding to Boeing's announcement. SES of Luxembourg, one of the world's largest commercial satellite operators, is internally discussing a proposal for low-mass communications satellite relying entirely on electric propulsion. Airbus announced that they contracted to build up to two communications space craft which are Eutelsat and SES, with all-electric propulsion system in 2014. One of these satellites, Eurostar E3000 (fig. 2) will be launched by Ariane5 in 2017. Eurostar E3000 has 5kW class hall thruster.

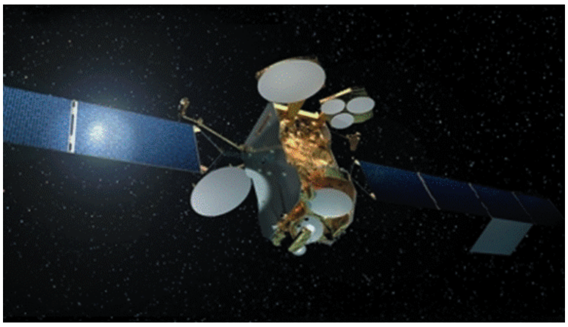


Fig. 2 Airbus Eurostar E3000

B. International coordination mission

The International Space Exploration Coordination Group (ISECG) developed by fourteen space agencies in May 2007 released the first version of the Global Exploration Roadmap (GER) in September 2011 and released updated version August 2013. The GER introduces a long range strategy for future mission scenarios of human exploration of Mars. Fig. 3 shows long range strategy. The roadmap reflects a common long-range human exploration strategy that begins with the ISS and expands human presence into the solar system, leading to human missions on the surface of Mars. It focuses on the first steps in implementing this strategy: utilizing the ISS, continuing to expand the synergies between human and robotic missions, and pursuing discoverydriven missions in the lunar vicinity that evolve capabilities and techniques needed to go further. By taking these first steps, missions into deep space and the Mars system would be enabled in a sustainable manner.

The studying about in-space propulsion system proceed toward the realization of these scenarios. In the “Asteroid Next” scenario, the Solar Electric Propulsion (SEP) is focused on as first candidate. The design reference mission assumes to transport the crew and its associated systems to the targeted NEA and back by the use of a combination of SEP and advanced cryogenic propulsion stage (CPS).

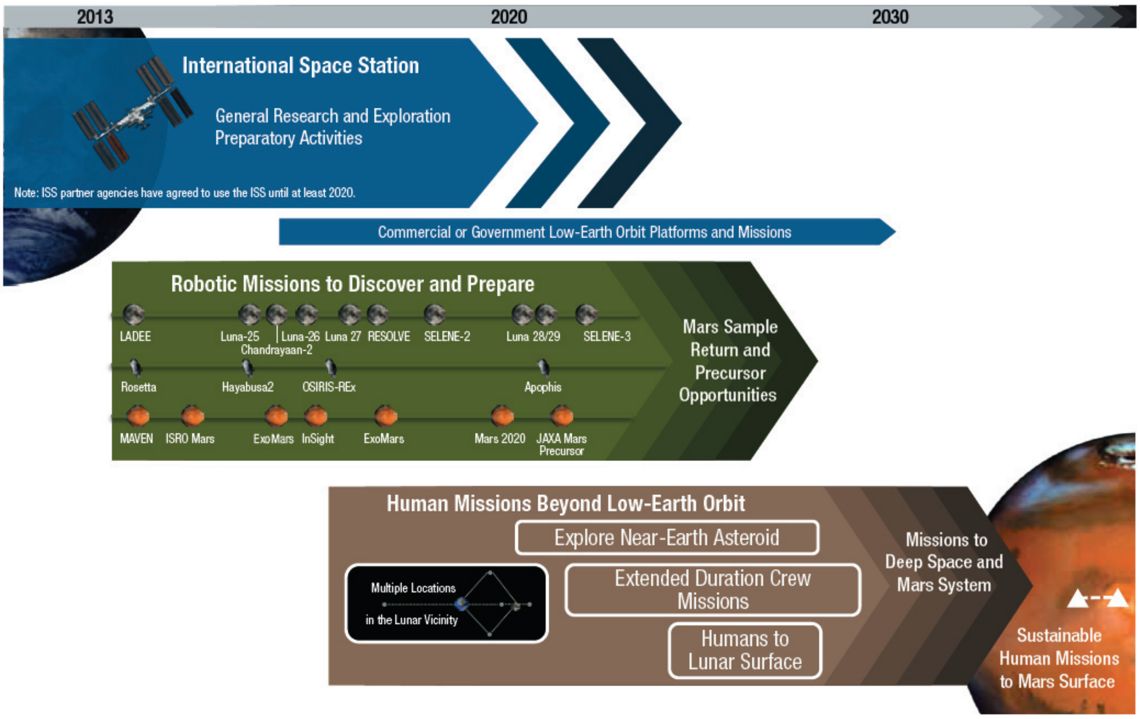


Fig. 3 Long-range strategy

III. Japan status and new frame work

C. Current status in Japan

Japan has track records in flight verification of ion thruster and MPD arcjet in Engineering Test Satellite (ETS) series and Space Flyer Unit (SFU). In addition, advanced technology about electric propulsion was shown to the world by the success of Hayabusa mission. However, there have been little study about high power electric propulsion system for in-space propulsion. Depending on the 702SP success, all-electric satellites have the potential to be accelerated to put into practical use in the near ter. Beyond that, GER may be realized in the near future.

If Japan would not promote the research and development about high power electric propulsion system, Japan will weaken the electric propulsion technique and may lose our presence in international coordinate mission. Japan needs to define the target mission and technical roadmap, and promote the improvement of electric propulsion continuously.

D. Framework for research and development

Active promotion of cooperation among industry, academia, and government is necessary to concentrate the knowledge and experience over the years in Japan. In 2011, JAXA has organized a workshop on “In-space propulsion” to share the mission and technical roadmap, and promote the research and development about high power electric propulsion system. The community consists of JAXA, twenty three universities and four companies.

JAXA and these universities conduct cooperative research on various thrusters, for example, Hall thruster and MPD thruster, and peripheral equipment like vacuum chamber. Each research is evaluated by the community in the annual progress workshop and, take selection and concentration.

IV. Roadmap and R&D activity in “In-space propulsion” work shop

In the in-space propulsion workshop, the community has discussed the reference mission and technical road map to define the R&D goal. In parallel, each research and development theme have been done.

E. Mission roadmap

Table 1 shows the three reference missions as mission roadmap.

<u>Phase 1; Transportation to GEO</u>

To catch up with world all-electric satellites, orbit transfer to GEO by only electric propulsion is the first target until about 2020 as R&D. It is assumed that the satellite weigh about 2,000kg is transported to GEO by a 5kW-class thruster.

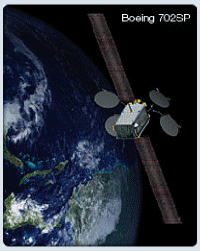
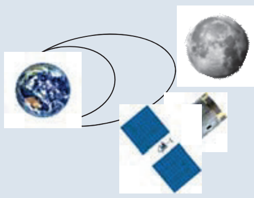
<u>Phase 2; Transportation to EML</u>

Next phase is transportation to Earth-Moon Lagrange Point (EML). ISS Experts Working Group (IEWG) has discussed transportation of ISS module from LEO to EML. In the GER, EML is thought to be an important transfer point. Phase 2 will be achieved by growing a thruster in power in power or clustering some thrusters which are verified in Phase 1 until about 2020.

<u>Phase 3; A part of GER, SEP</u>

The final mission goal is development of candidate for SEP in Asteroid scenario until about 2028, which transfer some goods to asteroid. It is assumed that total thruster power is about 160kW, total weight is about 180,000kg and mission time is about 9,000 hours.

Table 1. Mission roadmap

Schedule		~2020	2018~2020	2028
Mission		Transportation to GEO	Transportation to EML	Asteroid Next scenario
System Reference	Image			
	Thruster Property	Total Power : 5 kW Isp : 1900sec Total Thrust : 0.25N	Total Power : 50 kW Isp : 1900sec Total Thrust : 2.5N	Total Power : 160 kW Isp : 2000sec Total Thrust : 8.2N
	Weight Distribution	Total Weight : 2ton -Propellant : Xe 0.27ton -Paddle/EP system : 0.5ton -Structure/Avionics/Mission Equipment/etc : 1.2ton	Total Weight : 9ton -Propellant : Xe 3.1ton -Paddle/EP system : 2.3ton -Structure/Avionics/etc : 3.6ton	Total Weight : 18ton -Propellant : Xe 12ton -Paddle/EP system : 2.2ton -Structure/Avionics/etc : 3.8ton
	Mission Time	5000hr	6400hr	9000hr

F. Technical roadmap

Fig. 4 shows the technical roadmap. In the workshop, Hall thruster and MPD thruster have been studied mainly as major candidates for in-space propulsion. Besides thruster head, peripheral devices, for example, cathode, solar cell, and buttery are research. JAXA has been considering test facility too. Each research will be shown in next chapter.

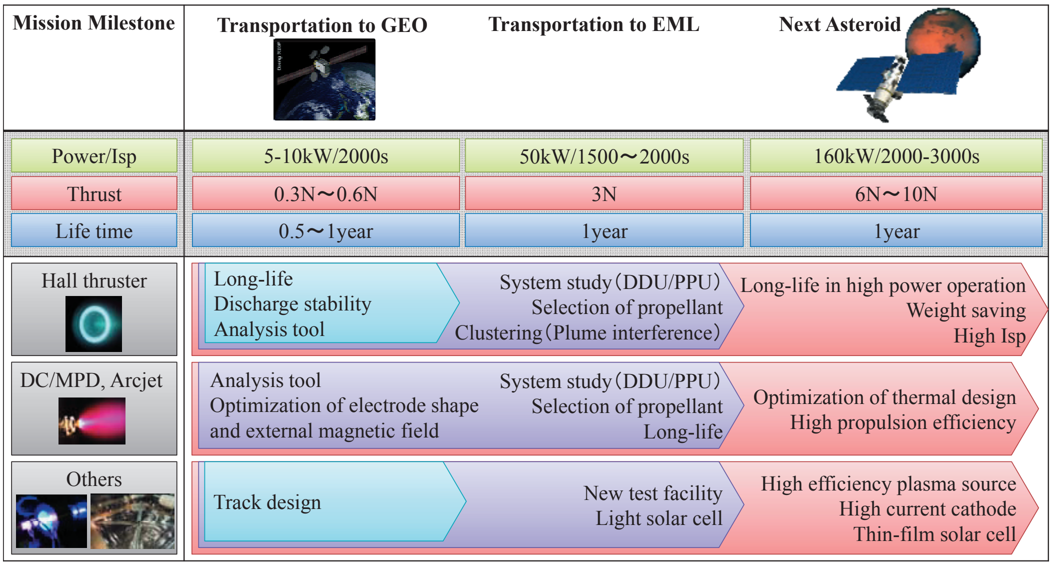


Fig. 5 Technical roadmap

In phase 1, it is necessary to address the challenges which small power thrusters have. For example, discharge instability and life extension in hall thruster and optimization of magnetic field in MPD thruster. In phase 2, thruster power increases dramatically. Therefore, it is necessary to consider power supply system for example direct drive unit (DDU) or power processing unit (PPU). In addition, propellant should be selected taking account of propulsion performance, weight and cost. In phase 3, thrusters need high performance and optimization of thermal design to achieve the mission requirement. Besides, it is necessary for peripheral device to be more efficient and powerful.

G. JAXA Collaborative research

Hall thruster

Hall thruster is the leading candidate for in-space propulsion because of their high efficiency thrust and Isp. NASA suggests a 30kW-class Hall thruster clustering ten thrusters; total power is 300kW, for SEP. in Japan, many universities have studied about Hall thruster and 5kW-class Hall thruster has been developed by Mitsubishi Electric Corporation. However Japanese hall thrusters have not been proven in space. Also, all major satellite bus rather than Boeing 702SP are developing all-electric satellites with hall thruster.

JAXA has been conducting cooperative research on Hall thruster with The University of Tokyo and other four universities. In the research, anode layer hall thruster has been studied. TALT-2 developed by the University of Tokyo is 5kW-class thruster which reach thrust efficiency 60% when Isp is 2000s. Fig. 6 shows TALT-2 operating. Additionally, plume interference by clustering have been researched. Along with the thruster head, peripheral device, for example high power cathode and smart power supply, have been researched too. Furthermore, orbital analysis and cost analysis have been conducted.

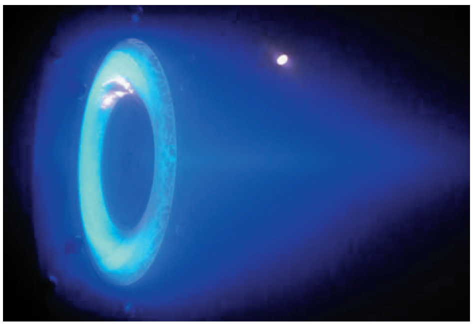


Fig. 6. TALT-2 operating with krypton

MPD thruster

MPD thruster or DC arcjet are better suited for high power thruster because they are very simple system and light weight. Moreover they can operate with low voltage, so it is possible to reduce power supply weight. Taking account of total weight, this advantage have to overcome the disadvantage; low thrust efficiency as a candidate for in-space propulsion. Japan has many research and development records and experimental proof in space.

JAXA and universities have been conducting cooperative research on various type of MPD thruster or DC arcjet. Nagoya University studies an applied-field MPD Thruster with hollow cathode and multi channel thruster toward high power. Tohoku University studies the thruster which has superimposed-field with magnetic coils. Osaka Institutes of Technology studies MPD thruster which has applied-field with permanent magnet. JAXA studies MPD 20 ~ 30 kW-class thruster which has big power supply capacitor.

V. Conclusion

JAXA has organized a workshop on “In-space propulsion” , with twenty three universities and four companies, to share the mission and technical roadmap, and promote the research and development about high power electric propulsion system. The community hope widespread participation to promote electric propulsion research and development for in-space propulsion, and realize the SEP as a part of international exploration mission.

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