RESEARCH INTRODUCTION

Aiming at lightweight, high-efficiency solar cells

Making satellite components as light as possible

Rockets lift off into the sky with a massive roar. At their tip, a "satellite" is stored within a shell called a fairing. A satellite carried by the H-IIB launch vehicle (our largest vehicle with a total length of 56.6 meters and a weight of 531 tons) into low Earth orbit at an altitude of about 400 kilometers has a load capacity of about 16.5 tons, only about 3% of the total rocket weight at liftoff. It is quite difficult to carry a satellite into space against gravity. For that reason, various weight-reduction features are being devised for satellites.

A satellite is equipped with "solar cells" that provides the power necessary for operation. The power requirement of a satellite is basically determined by its mission. In other words, if we are able to increase the "power-to-weight ratio", which is the ratio of the electrical power generated to the solar cell weight, satellites can be designed to be more lightweight, and more equipment for observation and testing can be installed.

"Cargo", such as a satellite, is stored within the fairing at the tip of the launch vehicle.

Fig.1 Launch of the domestically manufactured H-IIB launch vehicle

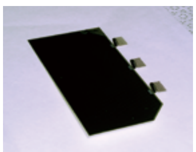
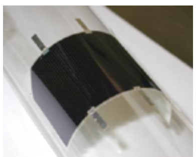
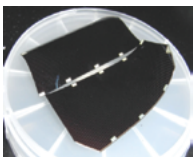
Making a lightweight "solar array"

Triple-junction solar cells with three power-generating layers are used in the ultrahigh-speed Internet satellite "Kizuna", launched in 2008, and the greenhouse gases observing satellite "Ibuki", launched in 2009. In order to achieve a lighter weight while maintaining the "conversion efficiency" of 25% to 30% for multi-junction solar cells, we are proceeding development of a solar cell with two power-generating layers and succeeded in the development of a dual-junction thin-film solar cell with 25% conversion efficiency. (Table)

By simply applying paper-like thin-film solar cells to the existing support (solar panel), we were able to increase the power-to-weight ratio from the previous 50 W/kg to 80 W/kg.(Fig. 2) However, making a lightweight solar array is the key to aiming for an even higher value. A lightweight solar array could be achieved if the plate-type structure of the panel can be modified to a frame-type structure. Currently, we are continuing research for achieving a power-to-weight ratio of 150 W/kg.

The solar array must be stowed small enough to be stored in the fairing and later deployed in space. Therefore, smooth deployment of the panel is targeted by mounting thin-film solar cells to the frame-structured panel to achieve a lighter weight as well as by providing a pantograph deployment function. (Fig. 3) With this deployment method, the stiffness of the solar array can be increased since the panels become

Table: Performance comparison of solar cells

	Triple-junction solar cell	Dual-junction thin-film solar cell	New triple-junction thin-film solar cell
Weight of 1 cell*1	3.2 g	0.2 g	0.3 g
Conversion efficiency (AM0*2, beginning of life)	25 ～ 30 %	25 %	30 ～ 32 % (Target)
Thickness	0.15 mm 	0.01 mm 	0.015 mm 

*1 Cell : Minimum unit for solar cells
*2 AM (Air mass) : Path length of sunlight through the atmosphere. Since there is no atmosphere to pass through in space, the AM value is 0.

immobilized by the pantograph structure after being deployed.

Unknown until flown in space

We are continuing research on increasing the efficiency of thin-film solar cells. We can increase the conversion efficiency by increasing the number of power-generating layers. Therefore, we are continuing research and development of a "new" triple-junction thin-film solar cell with another power-generating layer-which differs from existing triple-junction solar cells-and increased efficiency between 30% and 32% while maintaining its thinness. (Table) By constructing this solar cell as a frame-shaped panel, we believe that we can further increase the power-to-weight ratio.

Whether or not the developed solar cell can demonstrate the expected efficiency will be confirmed in a ground test using various testing equipment simulating space conditions. However, testing in space is more reliable to determine the actual performance of newly developed solar cells. Focusing on a 2013 launch, JAXA is continuing development of the space telescope for planetary observation "SPRINT-A" for observing planets such as Venus, Mars and Jupiter. SPRINT-A will be equipped with a space telescope for planetary observation, but we plan to demonstrate the solar cells under development in space by mounting them on the tower supporting the telescope.

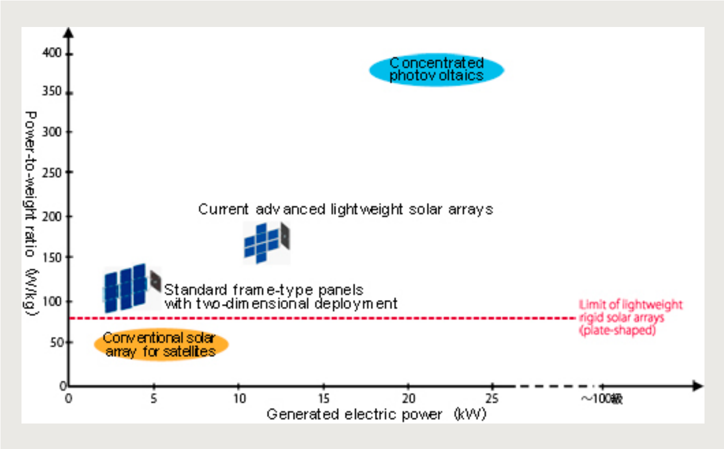


Fig.2 Development of lightweight solar cells

We are considering various configurations for the solar cells. One of these is "concentrated photovoltaics", where the solar cell area is reduced by using a lens to concentrate the sunlight. With this method, since the solar cell can be miniaturized, the power-to-weight ratio is believed to be improved and a larger electrical output will be achieved. In addition, this leads to a cost reduction since a solar cell for space is very expensive. Research has already begun in the United States, and we are continuing to study if concentrated photovoltaics can be used in space.

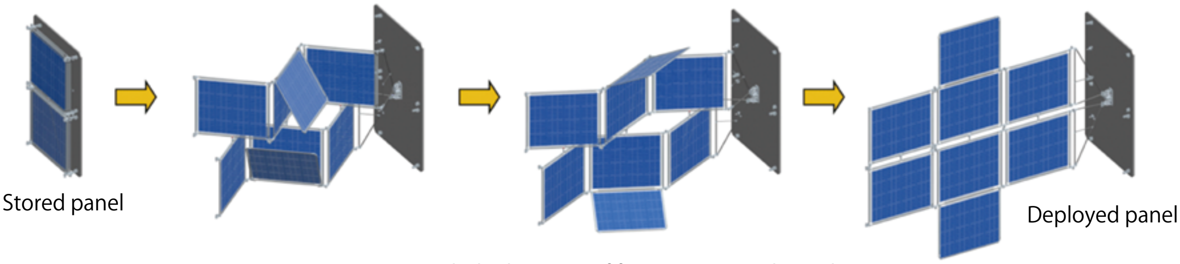


Fig.3 Pantograph deployment of frame-structured panel

[Space Power System Group]

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RESEARCH INTRODUCTION

Realizing a super-low-altitude artificial satellite

Increasing visual acuity of a satellite by lowering its orbit

There are various types of "earth observation satellites", which observe every part of the globe from space. JAXA has launched earth observation satellites such as the greenhouse gases observing satellite "Ibuki", which monitors carbon dioxide, regarded as the principle cause of global warming, as well as the advanced land observing satellite "Daichi", which is focused on mapping and resource surveying.

Many earth observation satellites observe Earth by traveling in an orbit that passes the North and South Poles at a right angle to the equator; this is at an altitude between 600 and 800 km. From that height, Earth is observed with an optical telescope. If the altitude of the satellite could be lowered, the "resolution", i.e., the visual acuity of the telescope, could increase since Earth would be closer. For example, if the altitude of a satellite equipped with an optical telescope having a resolution of 2.5 m was lowered from 800 km to 200 km, an object of about 60 cm could be distinguished. (Fig. 1)

In addition, there is the problem that the laser, when it is used for observation, becomes diffused because of the high altitude. However, by lowering the satellite altitude, this diffusion can be suppressed, enabling high-accuracy observation. This is another advantage of lowering the orbit altitude.

How can atmospheric drag be overcome?

Since 2006, JAXA has been studying development of an artificial satellite that orbits at a low altitude of about 200 km. During this time, we have identified two problems that must be resolved. One is "atmospheric drag". Space is generally defined as beginning from an altitude of 100 km, but, in fact, it is very unclear at what point the sky ends and space begins. By definition, the target altitude of a super-low-altitude satellite, 200 km, is in space, but there is still some small measure of atmosphere. Since this atmosphere creates resistance, a satellite would fall down to Earth in a few days without any thrust. Therefore, a super-low-altitude satellite needs an engine that produces thrust.

Unlike when launching an artificial satellite, flying a satellite at a low altitude does not require a large thrust. It would be enough to generate a thrust that counteracts the atmospheric drag. However, since the satellite will be used for a long time on a specific orbit, a fuel-efficient engine that can generate thrust for a long period of time is ideal. There is an engine suited for this task. The "ion engine" is used to maintain the north-south orbit by geosynchronous orbiters such as the Engineering Test Satellite VIII, "Kiku-8".

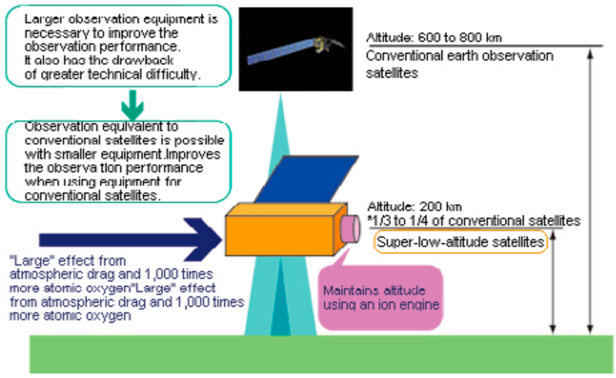


Fig.1 Concept of super-low-altitude satellites

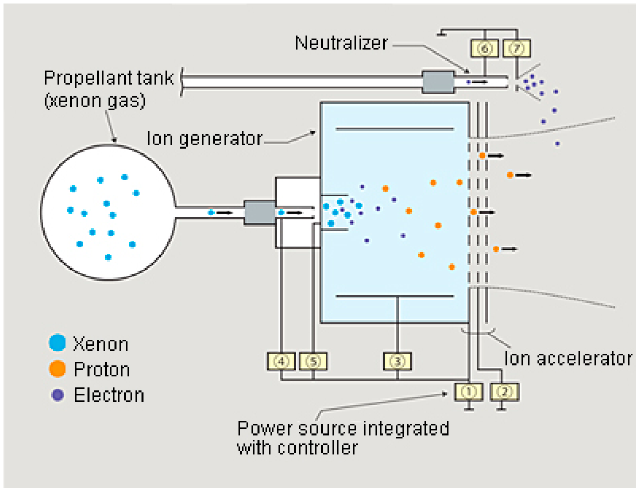


Fig.2 Ion engine

The ion engine produces thrust through the reaction force obtained when ions accelerated by an electrical force are expelled. It consists of an "ion generator" (generates ions from a propellant such as xenon), an "ion acceleration system" (accelerates those ions), a "neutralizer" (emits electrons for neutralizing the ions expelled into space), seven "power sources" (operate the above three sections), and a "controller" (controls the power sources). (Fig. 2)

The problem with oxygen when it becomes an atom

At a high altitude, oxygen in the atmosphere becomes atomic oxygen, which occurs when the two atoms separate. Atomic oxygen is an extremely strong oxidizing agent and may cause malfunctions in satellites. Since there is nearly 1,000 times more atomic oxygen at an altitude of 200 km than at 600 km, its effects are a concern. However, the reality of how it affects the satellite surface or interior is not clearly known.

Resolving the two problems of atmospheric drag and atomic oxygen is the key to realize a super-low-altitude satellite. Therefore, we are researching and developing the "super-low-altitude test satellite (SLATS)" (Fig. 3) with the objective of demonstrating how to keep a super-low-altitude orbit with the ion engine and obtaining distribution data for atomic oxygen. In order to reduce the atmospheric drag as much as possible, the ion engine mounted onto SLATS has been designed to be compact by building the operation controller into the power source as well as using the newest materials for parts. In addition, it is equipped with various new developments enabling flight at a super-low altitude, for example, functions that allow autonomous operation of the ion engine through the on-board use of detected orbit data, since the communication time with the ground station is reduced. For maintaining the orbit, we have found that a circular orbit can be stably maintained with thrust on/off operation for each revolution, and the satellite is expected to operate in orbit with that principle applied. The orbit keeping test period for SLATS is scheduled to be about 100 days. We will conduct tests of 7 to 50 days each at altitudes between 250 and 180 km and obtain the necessary data for practical use in addition to photographing Earth using optical sensors. Focusing on a launch in 2013 (JFY), we are currently conducting performance tests of the ion engine hardware. Moreover, with an eye toward practical satellites after SLATS, we are conducting research to extend the service life over 20,000 hours.

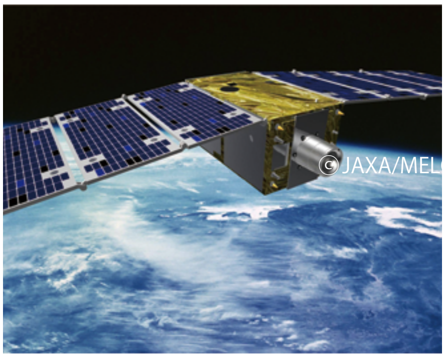


Fig.3 Super-low-altitude test satellite "SLATS"

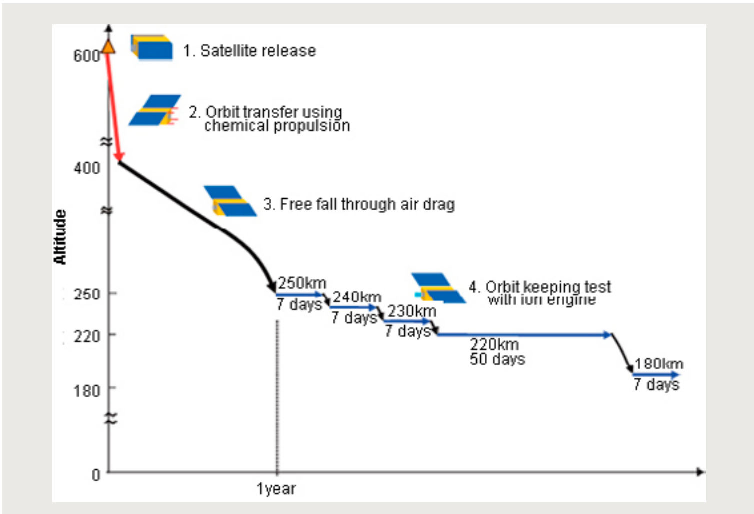
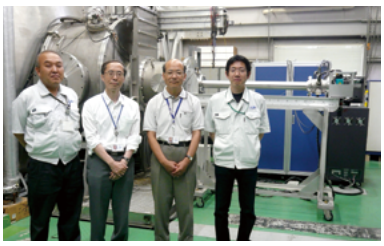


Fig.4 SLATS testing schedule (planned)



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