Development of the World's Highest-Performance Thin Membrane Solar Array Paddle

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Abstract

Solar array paddles mounted on satellites are required to be as lightweight as possible and capable of supplying high power. The NEC Corporation has been developing thin membrane solar array paddles (TMSAP) in collaboration with the Japan Aerospace Exploration Agency (JAXA) and aims to achieve the world's highest power-to-weight ratio of 150 W/kg or more for the power generated. The TMSAP, which greatly reduced weight by using a new structural method, has been confirmed to have attained the targeted performance with both the ground and on-orbit demonstration models. The newly developed TMSAP is expected to play an active role in various space development projects, such as deep space exploration and satellite constellations. This paper introduces the features of the TMSAP, its development history including on-orbit demonstrations, and perspectives on future development.

Keywords

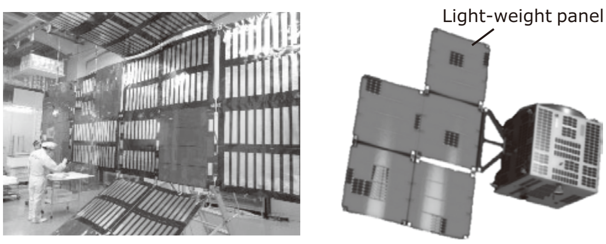
Satellite, solar array paddle, thin membrane, light weight, high power

1. Introduction

NEC has a rich and diverse track record in the development of satellites, starting with Japan's first satellite Ohsumi launched in 1970. We continued with the asteroid probe Hayabusa, which made the news when it returned with samples.

The solar array paddle is a device with the important function of converting solar light into electric power and supplying the satellite with this power. NEC has developed various solar array paddles to meet the needs of satellites, and recent solar array paddles are required to generate a high power-to-weight ratio (W/kg) to supply a high power output with their light weight.

Against this backdrop, NEC started the development of thin membrane solar array paddles (TMSAP) in 2009 with the goal of achieving the world's highest power-to-weight ratio for the power generated (W/kg) by effectively utilizing thin-film solar cells that have the unique feature of being thin and flexible (**Fig. 1** & **Fig. 2**). The development was continued in collaboration with JAXA,



(a) Ground demonstration model (b) On-orbit demonstration model

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Fig. 1 Thin membrane solar array paddle developed by NEC and JAXA.

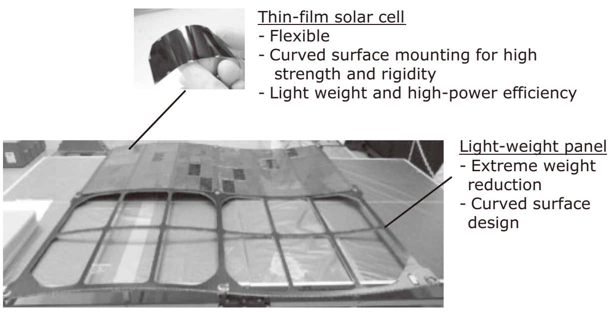

Fig. 2 Light-weight panel (View during fabrication).

and an on-orbit demonstration model was launched in 2019 to confirm its performance in space[1].

The rest of this paper introduces the features of the thin membrane paddles, the development history including an on-orbit demonstration, and perspectives on approaches for future development.

2. Outline of Thin Membrane Paddle

2.1 Development target

The target when developing the thin membrane paddles was to achieve the world's highest level of performance with a power-to-weight ratio of 150 W/kg or higher for the power generated. As shown in **Fig. 3**, this is two to three times better than the current mainstream solar array paddle system at beginning of life (BOL).

2.2 Development concepts

Considering the possibility of sales expansion in the future, the thin membrane paddle was designed to differentiate itself from competitors based on the following concepts.

The first is a system that inherits the satellite mounting interface from conventional paddles and can be easily replaced. High-performance paddles made by other companies have their own unique method of storing solar cells, such as rolling them up like roller shades, which requires a change in the satellite interface. On the other hand, the thin membrane paddles have the same interface, making it easy to use them on NEC's satellites as well as on other satellites in the world.

The second is the versatility and scalability that ensures flexibility to meet the power requirements of both small and large satellites. High-performance paddles from competitors are intended for large satellites and are scalable to handle large amounts of power, while the thin membrane paddles are differentiated by their compatibility with small satellites and spacecraft, which are expected to increase in number in the future.

2.3 Features of thin membrane paddle

This section introduces three main features of the thin membrane paddle.

2.3.1 Light-weight panel for high power-to-weight ratio

As shown in **Fig. 4**, the honeycomb panel is an area where we were effective in greatly reducing the weight so that it only accounts for half of the total mass of the TMSAP. In the thin membrane paddle, as shown in **Fig. 5** (b), the weight of the panels has been significantly reduced compared to the conventional flat panels shown in Fig. 5(a) by removing all but the minimum framework required to support the solar cells. Also, because simply framing a flat panel would lead to a drop in strength and

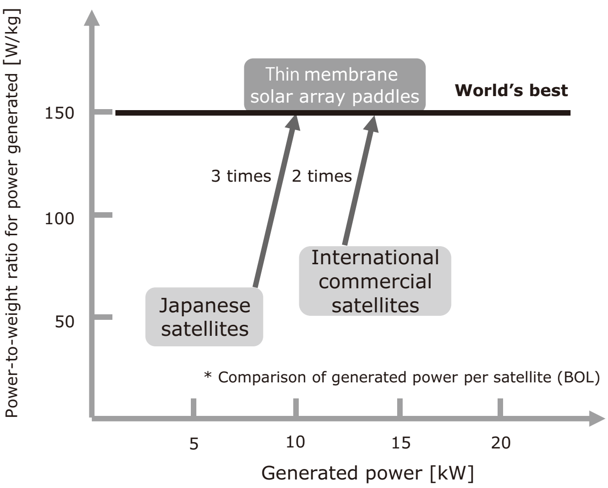

Fig. 3 Comparison of solar array paddle performances.

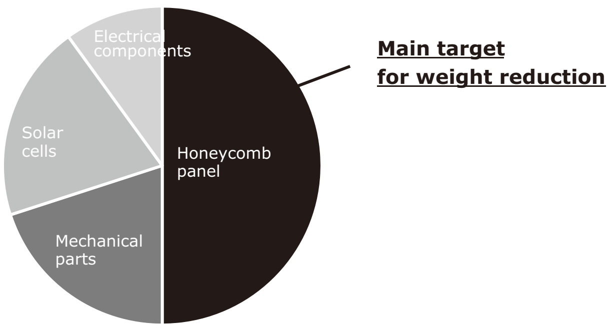

Fig. 4 Breakdown of typical weight of conventional solar array paddles.

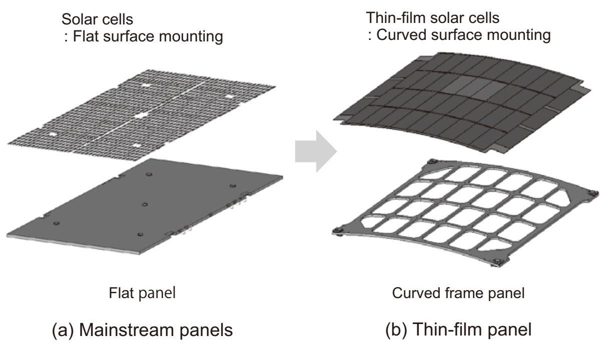

Fig. 5 Comparison of panels.

rigidity, we achieved the strength, rigidity, and lighter weight required for the paddles by mounting thin-film solar cells on a panel that has a slight curvature to enable flexible bending (Patents No. 6213806 & No. 6399391).

2.3.2 High extendibility

Thin membrane paddles are highly scalable and can be installed on a wide range of satellites from small to large. Specifically, the standard size is shown in **Fig. 6** (a) and this can be expanded to double the size as in Fig. 6 (b) or quadruple the size as in Fig. 6 (c). A maximum of 12 panels can be combined to flexibly meet the power requirements of satellites.

2.3.3 Light-weight parts made by 3D printer

Some parts with complex shapes were fabricated by using a 3D printer to reduce their size and weight. **Fig. 7** shows the parts fabricated in this way. They are the first metallic parts made by a 3D printer that are mounted on satellites after receiving quality certification from JAXA.

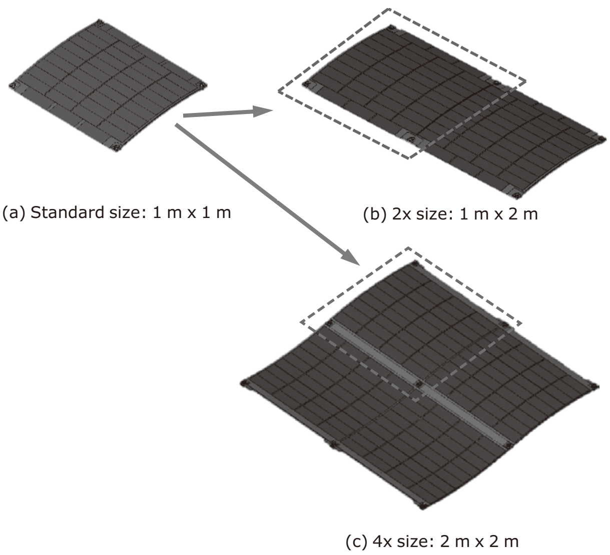

Fig. 6 Examples of panel extension.

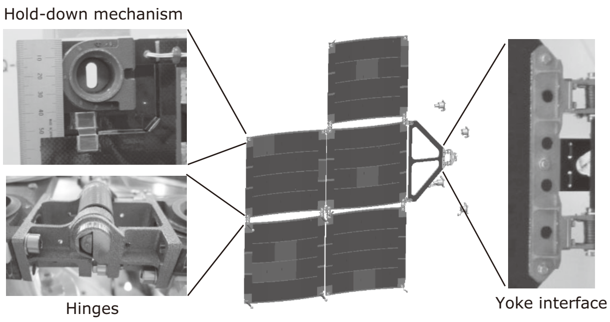

Fig. 7 Parts made by using a 3D printer.

3. Achievements in Development

The development of thin membrane paddles was started in 2009. After each component was verified, a light-weight panel was achieved in 2014, and a ground demonstration model that could generate the equivalent of 6.5 kW per wing was finished in 2015. After that, an on-orbit demonstration model was developed in about two and half years (**Fig. 8**). The following sections introduce the details of the evaluation of each demonstration model.

3.1 Test/evaluation of ground demonstration model

Because satellites are exposed to severe environments during launch as well as in space, the equipment mounted in them are subjected to endurance and functionality/performance tests on the ground simulating various environments. To be able to mount this equipment on the world's major rockets, this ground demonstration model has been tested under severe conditions that encompass the level of the launch environments of those rockets , and its resistance has been confirmed. **Fig. 9** shows images of the main mechanical system tests. The series of evaluation tests using the ground demonstration model confirmed that the target power-to-weight ratio of 150 W/kg for the power generated has been achieved.

3.2 Evaluation of on-orbit demonstration model

The on-orbit demonstration model named thin membrane solar array paddle (TMSAP) was mounted in the

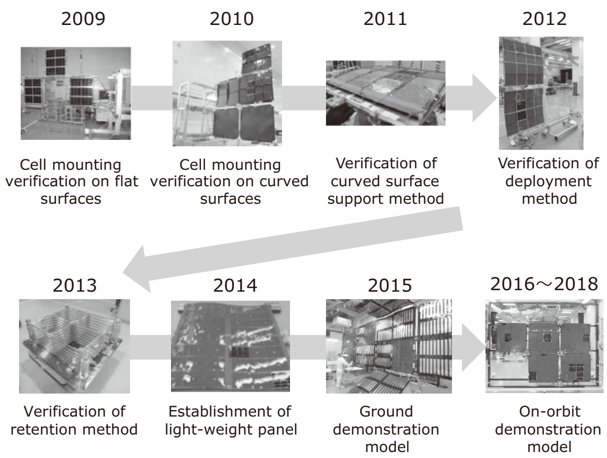

Fig. 8 Development history.

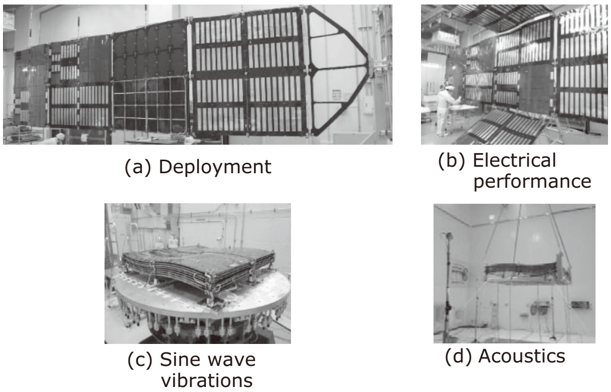

Fig. 9 Main mechanical tests of the ground demonstration model.

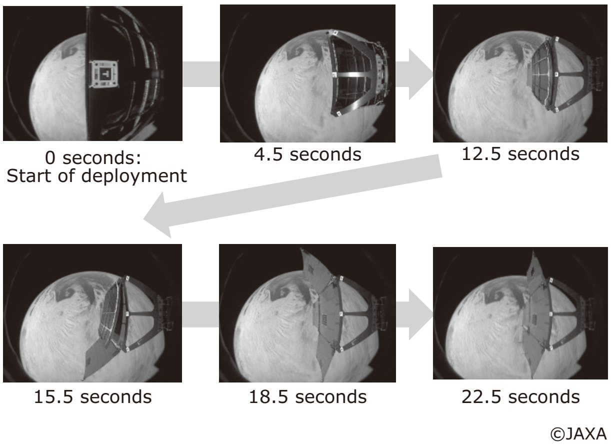

Fig. 10 Deployment sequence from satellite camera images.

rapid innovative payload demonstration satellite that was launched in January 2019. Deployment experiments of the thin membrane paddle and power generation experiments of the thin-film solar cells were performed on orbit, and both functions worked correctly until the end of operations in June 2010. The satellite camera image shown in **Fig. 10** confirms that the deployment sequence was consistent with the advance prediction[2)].

4. Future Initiatives

After an on-orbit demonstration of the thin membrane paddles, it was decided that the TMSAP would be mounted on the deep space probe named Destiny^{+} (demonstration and experiment of space technology for interplanetary voyage with Phaethon flyby and dust science) to be launched by JAXA in FY2024 as the first use in an actual satellite program. In this program, thin membrane paddles are cited as one of the key advanced technologies for deep space exploration and are expected to be used in various satellites and spacecraft in the future.

As of 2021, NEC and NEC Space Technologies, Ltd. are working together to reduce costs by using commercially available parts and building mass-production lines. These efforts are expected to enhance the attractiveness of the products and enable their adoption in satellite constellations in the future.

5. Conclusion

This paper has introduced the development of the thin membrane solar array paddles that were based on new concepts. By not being bound by convention and thereby reducing the paddles' weight to the absolute minimum, we have succeeded in achieving the world's highest power-to-weight ratio of 150 W/kg. In the future, we will contribute to space development by reducing the costs, improving the production capacity, and using the TMSAP on many satellites.

The authors of this paper would like to express their deep gratitude to JAXA for their kind guidance on the present development.

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